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CHAMBERS'S EDUCATIONAL COURSE—EDITED BY W. AND R. CHAMBERS.

NATURAL PHILOSOPHY.

(FOURTH TREATISE)

ACOUSTICS.

WILLIAM AND ROBERT CHAMBERS,
LONDON AND EDINBURGH.

Edinburgh :
Printed by W. and R. Chambers.

NOTICE.

The following treatise is intended to present a systematic exposition of the nature of Sound, the mode of its production, and the laws which determine its propagation. Great care has been taken to render the treatment, both in point of expression and sequence, as simple and intelligible as the nature of the subject will permit; while under most of the sections the laws are further illustrated by means of examples, diagrams, and descriptions of actual phenomena.

CONTENTS.

ACOUSTICS.

GENERAL EXPLANATIONS.

1. That branch of science which treats of the nature of sound, the mode of its production, and the laws which determine its propagation, is termed *acoustics*, from a Greek word signifying *to hear*. The phenomena of sound are of great interest, whether we consider those that are natural—as the voices of animals, the purling of the stream, and the rushing of the waterfall; or those that are artificial—as the varied sounds of musical instruments. It must therefore be an attractive inquiry to ascertain the cause of these phenomena; to discover by what organic apparatus, and through what medium, the human voice, for example, is capable of conveying even the thoughts of one individual to the mind of another—a process which we would consider to be perfectly astonishing, were it not constantly familiar to us; and to determine what are the remarkable relations that subsist among those artificial sounds, arranged and regulated by the rules of musical composition, by which we are enabled to express, and that often powerfully, a variety of our strongest feelings and deepest sentiments.

2. The atmosphere which envelops the earth, and in which all terrestrial beings are immersed, as it were, at the bottom of an ocean, is the great vehicle for conveying sound. When anything contained within it is violently struck, so as to be put into a tremulous motion—that is, to vibrate—it communicates vibrations to the adjoining air, and these are but the commencement of a line of waves all around, extending to great distances. In this manner a body can act upon things far removed from itself. Many other substances, however, besides

air, are capable of conveying sound. Every body possessing elasticity exhibits this quality; it being by virtue of its elasticity that atmospheric air is a sounding medium. Hence solids and liquids may have the same property.

3. If an elastic spring be fixed at one extremity, and the other extremity bent from its natural position of rest, and then set free, it will move backward and forward with a degree of rapidity dependent on its length and thickness, its density and elastic force; and its vibrations will be *isochronous*—that is, of equal duration, whatever be their extent. As the simplest case of propagation of waves of air, suppose the spring is fixed at one end of a long tube, these waves will be propagated along the air contained in it with the same velocity as in unconfined air. When the extremity of the spring during a vibration is moving in the direction of the tube, it suddenly condenses the air before it, and when it vibrates back in the opposite direction, it rarefies the air immediately contiguous to the previously condensed portion; and these two portions of air, extending from the extremity of the tube to a certain distance within it, are equal, and together compose a *wave*, whose length is entirely dependent, not on the extent, but on the duration of the vibration of the spring. At every *complete vibration* backward and forward of the spring, a similar and equal wave is propagated, and a consecutive series of such waves constitutes what is technically termed an *undulation*.

4. When the number of vibrations in any given time—as a second, or the number of waves that reach the ear in a second —is confined within certain limits, the sensation of *sound* is excited. Waves capable of producing sound are called *sonorous waves*. The gravest sound that is perceptible to the human ear is produced by 32 half vibrations in a second, and is like a *whisper;* the highest, on the other hand, is caused by as many as 16,384, the resulting sound being like a *hiss*. There is, however, some difference in the compass of audible sounds by different ears. Some persons, for instance, cannot hear the shrill note of the grasshopper or cricket.

VELOCITY AND INTENSITY OF SOUND.

5. If the air were dry, and its temperature at freezing, the velocity of sound would be 1090 feet per second. When the air is in a mean hygrometric state, and the temperature 60 degrees, the velocity is 1125, and when the temperature differs from 60, if the number 1·25, or $1\frac{1}{4}$ feet, be multiplied by the difference, and the product added to 1125, or subtracted from it—according as the temperature is greater or less than

60—the sum or remainder will be the velocity of sound for that temperature.

6. Example.—Find the velocity of sound when the temperature is 54, and also when it is 66:—

Here the difference between 54 and 60 is 6, and the product of 1·25 by 6 is 7·5; hence the velocity is the difference of 1125 and 7·5, or 1117·5 feet per second.

For the temperature 66, the product is the same, or 7·5, which is to be added to 1125, and the sum 1132·5 is the required velocity.

7. The flash of a cannon is seen for some seconds before hearing the report. At the distance of half a mile, for instance, the report would be heard $2\frac{1}{3}$ seconds after seeing the flash; for the distance, 2640 feet, divided by 1125, gives $2\frac{1}{3}$ very nearly. So a flash of lightning is generally seen several seconds before hearing the thunder; and as the agitation of the air producing the sound of thunder begins at the instant of the flash, the distance of the thundery discharge will be found by multiplying the number of seconds in the elapsed interval by 1125. So the distance of an inaccessible rock or wall that causes an echo, can be computed by observing accurately the interval between the sound and the echo; for the elapsed time will correspond to double the distance of the reflecting surface, as the waves must advance to that distance, and then return, before the echo can be heard.

8. Both the velocity and the loudness of sound are considerably greater when conveyed through certain liquids and solids than through air. Thus through water it moves with a velocity of 4708 feet in a second, or more than four times that in air; through tin it is $7\frac{1}{2}$, through copper 12, oak $10\frac{2}{3}$, beech $12\frac{1}{2}$, elm $14\frac{2}{3}$, and through brass and iron $16\frac{2}{3}$ times quicker than in air. A very weak sound—as the scratch of a pin, or the ticking of a watch—made at one end of a log of wood, can be heard by an ear applied at the other end, though it would produce no audible sound at the same distance in air. Savages apply their ear to the ground when they wish to hear any noise that is weak or distant, such as the approach of men or horses.

9. The intensity of sound, like that of light, heat, and the force of gravitation, varies inversely as the square of the distance from the centre of propagation; so that at double the distance, it is four times less; at triple the distance, nine times less; at ten times the distance, 100 times less. Sound, therefore, diminishes more rapidly in intensity than the distance increases, and soon becomes comparatively weak. The transmission of sounds is modified or altogether suspended

when aqueous meteors disturb the homogeneity of the medium through which they pass. The following is a fine illustration:—The British and American troops were encamped on either side of a river, and the outposts so near, that individual figures could be distinguished. A drummer was seen to appear on the American side, and though the motions of his arms were perfectly visible, not a sound was audible. It seemed to have been obstructed by a coating of newly-fallen snow, and the thickness of the atmosphere. The opposite effect is produced by glazed or hardened snow, ice, or water. Thus the sound of cannon was distinctly heard booming over the ocean at a distance of nearly 200 miles from the scene of action, in the famous engagement with the Dutch in 1672. A few years ago, the noise of artillery was heard at Calais and Dover, which proceeded from a field exercise of 12,000 troops at Denderleeuw, about twenty-five miles from Brussels—a direct line of nearly 130 miles. At a similar distance the sound of cannon was heard at sea, on the landing of the British troops in Egypt. The noise of the eruption of Tumbora, in the island of Sumbawa, in the Pacific Ocean, which continued active from April to July 1815, on the authority of Sir Stamford Raffles, was heard clearly in a circle whose radius was 850 miles, consequently over an area of 2,269,806 square miles. The roarings of Cotopaxi in 1744 were heard as far as Honda, on the Magdalena River, in New Granada, a distance of more than 600 miles. These extraordinary sounds must have been conveyed through the ground not by atmospheric pulses. According to Ellicot, the sound of the Niagara Falls is often audible twenty miles off; and that of the stupendous cataract of the Missouri first fell upon the ear of Lewis when seven miles from the waterfall. Sound may also be heard at sea at very great distances when collected by the sails of the vessel, and reflected to a focus. The following case in point is related by Dr Arnot:—"It happened once on board a ship sailing along the coast of Brazil, 100 miles from land, that the persons walking on deck, when passing a particular spot, heard most distinctly the sounds of bells varying as in human rejoicings. All on board listened, and were convinced; but the phenomenon was mysterious and inexplicable. Some months afterwards, it was ascertained that at the time of observation the bells of the city of St Salvador, on the Brazilian coast, had been ringing on the occasion of a festival: the sound, therefore, favoured by a gentle wind, had travelled over 100 miles of smooth water; and striking the wide-spread sail of the ship, rendered concave by a gentle breeze, had been brought to a focus, and rendered perceptible." Lieutenant

Foster conversed with a sailor across Port Bowen Harbour, in the Arctic regions, at a distance of a mile and a quarter. The human voice, it is stated, has been heard at the amazing distance of ten miles over water, from New to Old Gibraltar. It is stated that the voice may be heard on Table Mountain from Cape Town, about a mile off; and on the testimony of the late Dr Jamieson, he once heard the words of a sermon preached at the distance of two miles. The goat-herds of the Alps, by using a falsetto intonation, exchange sentiments nearly at a similar distance. The Arabs, whose extraordinary power of distinguishing impressions on the sands, and thereby reading the *news* of the desert, are likewise skilled in the detection of sounds at incredible distances. Expecting the arrival of a ship from India, the Arab will, morning and evening, hasten to the shore, and kneeling, listen for a few minutes with his ear upon the water. Suppose the ship at that moment 150 miles from land, he hears the signal-gun, or perceives the vibration of the ground, and setting off in his skiff, finds he was not mistaken.

DURATION OF SONOROUS IMPRESSIONS.

10. The duration of impressions of sound (as in the case of light) is a sensible period of time. If sounds succeed each other at intervals of one-twelfth of a second, they seem to be one continuous sound. The fact of sounds rapidly succeeding each other, forming an uninterrupted sound, is well known to the drummer, who, by a rapid quivering motion of his hand, gives at least twelve strokes with his drum-stick in a second, and the effect is that of a single continuous sound, like a musical note, which is itself only a rapid succession of single sounds.

NATURE OF WAVES OF AIR.

11. The nature of a wave of air in passing along a pipe is represented in the annexed figure, in which that half of the

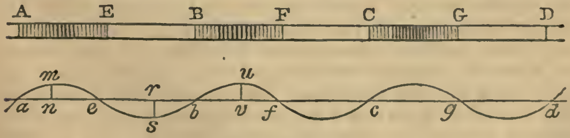

Fig. 1.

wave whose density exceeds the ordinary density of the air is strongly shaded, and the half that is of less than the ordinary

density is not shaded. Thus AB, BC, CD represent these waves, one-half of each of which consists of denser, and the other half of rarer air; AE is the denser half of the first wave, and EB the rarer half. In the second portion of the figure, *ab*, *bc*, *cd* represent the same waves, only the excess of the density of the more condensed parts above the medium density is represented at any point in the wave—as *n*—by the perpendicular line *nm* drawn to the curved line, and the defect of the density of the rarer half below that of the medium density at any point *r*, is denoted by the perpendicular *rs* drawn downwards to the curved line. The deviation of the waved line *amesbu* .... from the straight line *abc* .... indicates the deviation of the density from the mean density of the air along the line of the undulation. The wave moves with great rapidity, but the particles of air have a comparatively slow reciprocating motion, and to a very small extent on each side of their natural position of rest. The particles move, for instance, from the dense towards the rare portion, as from *n* towards *a* and *e*, and from *v* towards *b* and *f*, so that the effect is the same as if the condensation *ame* moved uniformly along the line *acd*, followed by a rarefied portion.

12. Solid elastic bodies of an elongated form, as strings and rods, have three kinds of vibration—*transverse*, *longitudinal*, or *tortive*. The *transverse* mode of vibration is like that of a string of a violin or piano, as in fig. 2. If the points CD are supposed to be the extremities of the string, and fixed, and if it be drawn a little out of its position of rest, as C*m*D, and then set free, it will vibrate to a nearly equal distance on the other side of the line C*n*D, and will continue in a vibratory state till it be gradually reduced to rest by the resistance of the air and its want of perfect elasticity. The *longitudinal* vibration is, in one case, exactly like that of the column of air O_3B, explained in art. 45. The vibration of *tortion*, or the tortive vibration, may be understood by conceiving a thin square rod of steel fixed firmly in a vice at one end, and twisted by a force applied at the other end; when set free, it will, by its elasticity, return to its original position, and by the circular momentum its particles have thus acquired, they will rotate nearly as far in the opposite direction, and again return; and thus the circular vibrations will be, like the other two sorts, continued for some time, till they gradually cease. A rigid rod of wood or metal is also capable of transverse vibrations, like an elastic cord when fixed at both ends, or when fixed only at one end, or when not fixed at all. These vibrations may be excited by means of a rosined bow. Longitudinal vibrations may also be excited in metallic rods, by

rubbing them in the direction of their length with a piece of rosined cloth, and in glass rods by moistened cloth.

13. The three kinds of vibrations can be easily exemplified by a simple apparatus. Thus C W is a brass wire suspended from the top of a stand at C, and kept tense by means of a weight W; LD is a movable clamp for securing any portion of the wire intended to vibrate transversely. Being thus secured at D, if it be drawn to a side at the middle *m*, it will exhibit the transverse vibrations. If the wire be previously made of a spiral form, the spiral being of small diameter, and the weight be raised, and then suddenly let fall, it will exhibit the longitudinal vibrations, the weight in consequence vibrating up and down. Again, if the weight be turned round several times, so as to twist the wire, and be then suddenly let go, the wire will perform the vibrations of torsion.

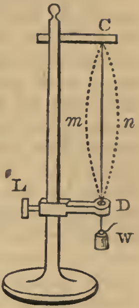

Fig. 2.

14. The cause of vibration is the elasticity of the vibrating material. Were it inelastic, it would remain dead after a stroke. When an elastic cord is fixed at both ends (fig. 3), and is drawn a little to a side, by its elasticity it is capable of some distension, which is essential to a transverse vibration. Forces of tension act upon it at every point, as at *v*, in the directions of a tangent to the curve. Take any minute portion of the cord, as *rms*, then it is acted on by forces of tension in the directions *rt*, *st'*, and its own weight downwards in the direction *mg;* for we may, without sensible error, suppose the weight of the elementary portion *rs* to be concentrated at its middle point, and that *rms* is rigid. By constructing a parallelogram *rvs*, the action of the two tensions, denoted by the lines *mr*, *ms*, will be equivalent to a single force *mv;* and were the string so heavy as to rest in the position S*m*T, the weight of the portion *rs* would be represented by *vm*. But the force of tension is in most cases immensely greater than the weight, and therefore the latter may be neglected; the only resistance, then, that the resultant of the tensions *vm* has to overcome, is

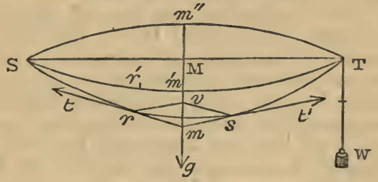

Fig. 3.

the mass of rs. Now when the point m is in the position m', say half way to M, the angle vrm is half the size, and the resultant vm half as great, and therefore the acceleration at m' is half as much as at m, since the mass of rs is invariable, at least if it be supposed that the vibrations are of small sweep. It thus appears that at any point of the cord, the force drawing it to its natural position is proportional to the distance of the point from this position; and it can be proved that the accelerating forces on every element are equal at equal distances from the line SMT. The same is true of all the other points; but when the forces that act on a body are proportional to the distances of its position from its state of rest or equilibrium, the body vibrates like a pendulum, *isochronously**—that is, the vibrations are of the same duration, whether large or small; so that whatever be the excursions of a vibrating cord within a certain limit, they are performed in equal times, and therefore cause waves of sound of equal length. The same is true of the vibrations of rods, whether entirely free, or fixed at one or both ends; and it is also true for longitudinal vibrations.

15. In experimenting with an elastic string stretched horizontally, it is usual to fix it at one end S (fig. 3), and to stretch it by means of a weight W attached to its other extremity, the string passing over a pulley at T; then ST is evidently the vibrating portion of the string. If the string possessed no elasticity, it is evident that it could not be stretched, and therefore it could not vibrate.

16. The square of the time of vibration of a pendulum is inversely proportional to the force acting upon it; or the square of the number of vibrations in a given time, as in one second, is directly proportional to this force. If, therefore, the force for one pendulum be four times that for another, the squares of the numbers of vibrations in a second will be as 1 to 4, or the numbers themselves as 1 to 2; if the forces are as 9 to 16, the numbers will be as 3 to 4; and so on. The same, therefore, is true for the numbers of vibrations of elastic cords.

17. EXAMPLE.—One string performs 120 vibrations in 1 second, and another is under the influence of a tension 4 times as great; what number of vibrations will the latter perform in a second?

The force 1 is to the force 4 as the square of 120 to the square of the required number of vibrations. Now the square of 120 is 14,400, and the fourth proportional to the three numbers 1, 4, 14,400, is evidently 57,600, which is therefore the

* See MATTER AND MOTION, article 268.

square of the required number of vibrations; the square root of this number is 240, the required number. A quadruple force, therefore, causes only a double number of vibrations.

18. If two strings are in every respect of the same kind, and stretched by equal weights, but one of them twice the length of the other, the latter will perform half as many vibrations as the former.

19. If two strings, the same in every respect, be stretched by weights in the ratio of 1 to 4, the number of vibrations produced by the action of the greater weight will be twice as many in a given time as by the smaller.

20. If the diameter of one string be double that of another of the same kind of the same length, and stretched by an equal weight, the thicker string will vibrate only half as fast as the thinner.

21. The last three theorems may be stated in general terms thus:—When two strings of the same kind and diameter, but of different lengths, are stretched by equal weights, the numbers of their vibrations in a given time are inversely as their lengths; when two strings are of the same kind and dimensions, but stretched by different weights, the numbers of their vibrations are directly proportional to the square roots of the weights; and when two strings of the same kind and length, but of different diameters, are stretched by equal weights, the numbers of their vibrations are inversely as their diameters.

HARMONIC DIVISIONS OF AN ELASTIC STRING.

22. When a string vibrates transversely in its whole length, it is found that its aliquot parts—as its halves, its thirds, and so on—also vibrate separately, and with a degree of rapidity exceeding that of the string itself, according to the principles just explained. An experienced musical ear is sensible of the higher notes produced, by the vibrations of these parts accompanying the fundamental or principal note produced by the entire string. These divisions of a string are called the harmonic divisions; the half length may, for convenience, be called the *second harmonic* division; the third part, the *third harmonic* part; and so on.

23. When a rope fixed at one end, and stretched by the hand at its other extremity, is agitated at equal short intervals of time, a series of waves will be formed along it, and it will at last assume the form of a string divided into a number of equal parts vibrating separately, the vibrations of every two consecutive parts being in opposite directions, and the vibrating parts

separated by stationary points, called *nodes*, or *nodal points*. Such a system of waves is termed a stationary undulation.

24. The form assumed by the undulation described in the last paragraph, can be communicated to a string vibrating in its *whole length*, by gently touching it at one of the nodal points. If it is wished to make it divide itself into two harmonic parts, this form is given by touching it in the middle point, which becomes a node; if into three harmonic parts, it must be touched at one of the corresponding nodal points; and so on for any other harmonic vibration.

25. That a string can vibrate in its whole length, and also at the same time in some of its aliquot parts, may be shown to be a possible and natural thing by the following considerations:—The whole string, supposed, when at rest, in a horizontal line, may be moving from right to left, its middle point being in a horizontal plane; while at the same time one of its halves may be seen sidewise moving up and down as if in a vertical plane, and of course the other half has a similar motion, only its vibrations would be in an opposite direction. As the half-string vibrates twice as fast as the whole, the air will receive two impulses from its vibrations up and down, in the time that it receives a single impulse by the whole string in a lateral direction; and consequently two musical notes are produced in the relation of octaves (art. 100). So a third of the string may be moving in an intermediate direction, producing a different note; though certainly the waves produced by the various kinds of vibrations will weaken each other, and produce in some parts a blending of sounds resembling a resonance (art. 67).

VIBRATION OF ELASTIC RODS.

26. Rods of wood, or metal, or of any other elastic materials, when fixed at one or both ends, or when free at both ends, are capable of transverse vibrations bearing a general resemblance to those of elastic strings, but observing very different laws. The vibrations of rods, however, are isochronous, as in the case of strings; and they vibrate either entirely or in parts, forming nodes of vibration like strings. For experiments on transverse vibrations of rods, they must be of uniform dimensions throughout their length—that is, either cylindrical, like wires, or square, or prismatic.

27. The simplest mode of transverse vibrations of a rod, is when it vibrates in its whole length with one end fixed, as in a vice. This sort of vibration is represented in fig. 4, in which VF is the rod in its position of rest, and VM, VN its posi-

tion when at the limits of a transverse vibration. The law of vibration in this case is this:—The times of the vibrations of perfectly elastic rods vibrating in their whole length, and fixed at one end, are directly proportional to the squares of their lengths; and the numbers of vibrations in a given time are therefore inversely as the squares of their lengths.

Fig. 4.

28. Example.—Two rods of the same material, and of uniform thickness, are respectively 2 and 3 feet long; required the ratio of their times of vibration?

The ratio of these times are directly as the squares of 2 and 3—that is, as 4 and 9; or the time of a vibration of the latter is more than double that of the former: so the numbers of vibrations of the former, compared with those of the latter in the same time, are as 9 to 4. If the former, for instance, performs 36 vibrations in a second, then 9 is to 4 as 36 to 16, the number of vibrations of the latter in one second.

29. When a polished metallic knob is fixed on the end of a vibrating rod, it is observed that the vibrations are seldom performed in one plane, as the bright point is seen to move in paths sometimes nearly circular, at other times elliptical and lemniscatic—that is, resembling the figure 8, or in very complex intersecting curved lines, perpetually changing their form and position.

VIBRATIONS OF ELASTIC PLATES, RINGS, BELLS.

30. When elastic plates of uniform thickness and regular figure are put into a state of vibration by means of a rosined bow, or by percussion, there is a series of nodal points regularly arranged in lines, called *nodal lines*. These are easily rendered visible to the eye by strewing the plates with fine sand, which, by the agitation of the vibrating parts, is removed from them, and accumulates along the nodal lines. They vary in form with the form of the plate and the part where they are put in vibration; the point at which they are held will always lie in at least one of the nodal lines.

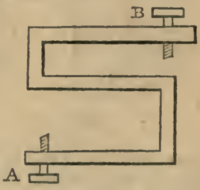

Fig. 5.

31. Plates may be considered as composed of straight fibres;

so that a rectangular plate, whose length is great compared with its breadth, would vibrate like an elastic rod, and would have nodal lines transverse to its length—that is, across it in the direction of its breadth, at exactly the same parts as the nodal points of a vibrating rod. The instrument used for holding the plates is a sort of wooden vice, like that in fig. 5, which can be fixed on a board or table by the lower screw A, and holds the plate by the upper one B.

32. If a square plate of glass or metal be held by the centre C, and be put into vibration by means of a bow applied near to one of its angles A, there will be two nodal lines passing through its centre parallel to its sides, and therefore perpendicular to each other. The sound thus produced is the gravest that can be obtained from the plate. The sound next in depth is produced when the plate is held at the centre as before, and the bow applied to the middle of one side. In this case the nodal lines are in the two diagonals of the plate.

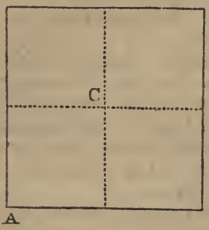

Fig. 6.

33. By holding the plate at other points, an unlimited variety of different nodal lines may be successively formed.

34. When the plate is circular, and the edge free, the nodal lines may be of two species—*diametral* or *circular*. The number of diametral nodal lines is always even, the least number being two. The reason why the number is even, is, that when one quarter (A E D) vibrates towards one side, the two contiguous quarters must vibrate in opposite directions; and in general every two contiguous divisions must vibrate in opposite directions, which cannot happen when the number of divisions is uneven. So, in the case of a ring, as A B C D, when one quarter (A B) vibrates outwards, its contiguous parts (A D, B C) must vibrate inwards, and it must divide itself into an even number of equal parts; and supposing the circular plate composed of rings whose quarters vibrate to opposite sides, instead of outwards and inwards, the nature of the vibrations of the plate will be easily understood.

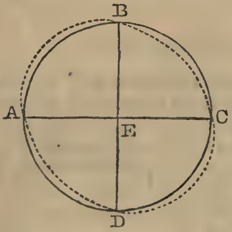

Fig. 7.

35. In the diametral species of nodal lines, the gravest sound is produced when there are two lines, the next grave when there are four, and so on.

36. The circular nodal lines are either one or two, concentric with the plate; or one with a single diametral line; or one with two diametral lines. These two types may degenerate into a variety of curved nodal lines, according to circumstances.

37. The immense variety of nodal lines that can be formed on a plate of any form, are proved to result from the superposition—that is, the co-existence of different modes of simple vibration, analogous to the simultaneous existence of the vibrations of a musical string, or of the air in an organ-pipe, and of their harmonies; or still more resembling the resultant note arising from the periodical coincidences of the vibrations producing two or more co-existing notes.

38. Nodal lines are found to exist in the air of a room when put into a uniform state of vibration by the sound of an organ-pipe, and these are observed by placing fine sand on any elastic tense membrane, as paper or parchment, which becomes agitated everywhere excepting in the quiescent parts.

39. The vibrations of a bell are exactly analogous to those of rings, and are easily conceived by considering it as composed of a series of rings parallel to its rim, and having, therefore, the same axis as the bell. The divisions will be equal portions formed by drawing lines from the apex to the points of equal division of the rim, and as in the case of rings, their number will always be even.

40. The parchment of a drum, cymbals, the tom-tom or gong, are familiar examples of sonorous plates.

STATIONARY UNDULATIONS IN CANALS AND PIPES.

41. When a series of equal waves are produced in a canal containing water, and bounded at one end by a plane perpendicular to its length, the reflected and direct series of waves, by mutual interference at equidistant points, destroy each other's influence in elevating or depressing the water at these points, and thus is formed a stationary undulation.

42. The mutual action of the opposing series of waves upon each other that causes this result is very easily understood. Let MEB (fig. 8) be the level surface of water when still in a canal, of which BH is the end; and let B*c*M, MSE be the elevation and depression constituting one wave, whose beginning has just reached the end of the canal. If the canal were unobstructed, the sinus of the wave in advance of EMB would at

the same instant have the position Bn'; but being reflected, it would actually, if not interfered with, be in the position BnM; and consequently, as the depressions of every point in

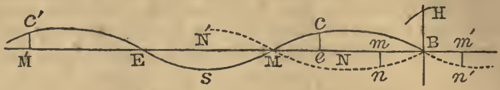

Fig. 8.

this half wave are equal to the elevations of the half (McB) of the other wave, the effect of their interference will be entirely to destroy the wave along the distance MNB, which would therefore cause the surface of the water to remain at its natural level over that space. But it is evident that this condition of the surface would continue only for an indefinitely short time, for the direct and retrograde motion of the two series of waves would immediately bring them into new positions, where they would not destroy each other's action except at certain points. It will not be difficult to ascertain the position of these singular points. One of them is in the *middle* of the *half wave* MB at N. For it has just been seen that the point N is brought to its natural level when B is the beginning of a wave. Take any point c in the surface of the elevation McB, and a corresponding point n in the reflected sinus; these points are evidently at the same distance from the middle point N; and consequently, since their motions are equal and opposite, they will both reach the middle point at the same time; and the elevation being exactly equal to the depression, the vertical motions will neutralise each other, and the surface at N will be in its quiescent position; and whatever other corresponding points are taken in the advancing crest and the retrograde sinus, the same effect will happen. Likewise, if MnB were an advancing sinus, and McB a reflected crest of a wave, the same consequence would ensue; the surface at N, therefore, is always stationary. It could be similarly shown that at N′, the middle of EM, also the surface is constantly at the same height. These stationary points or *nodes* are therefore at a distance from the extremity of the canal, equal to $\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{4}$, ... or generally an *uneven* number of quarters of the length of a complete wave EMB.

43. At the intermediate points M, E, ... between the nodes, are formed the *loops*, or alternating elevations and depressions. For when the middle of the crest Ec' of the succeeding wave would reach the point M, the middle of the crest McB of the

preceding one would, after reflection, just reach the same point; so when any point c' in the former wave would reach M, the corresponding point c in the same phase with the latter would exactly reach M after reflection; and in this way it is shown that every direct wave will meet the immediately preceding one, returning, after reflection, in the same phase at M and E, and all the other loops. When the middle points of the crests thus coincide at M, the elevation there will be twice as great as that of the original undulation before reflection; and when the middle of two sinuses meet, the depression would be twice as great as that of the original waves. The resulting undulation is called *stationary.*

44. There is an exact analogy between this action of water in canals and the motions of air in *organ-pipes*. In the vibrations of air, there are points called *nodes* and *loops*, and the horizontal motions of the particles of air are exactly like those of water; but instead of the terms elevations and depressions of waves of water above and below the mean level, *condensations* and *rarefactions* of the air above and below the mean density must be used.

45. Let FB be a close organ-pipe, of which FT is the foot, O_3T the mouth, and B the flat closed end. Let a system of undulations be excited in the pipe, exactly like the advancing system of aqueous waves in fig. 8; let the system advancing from O_3 to B be represented by $O_3 r$, of

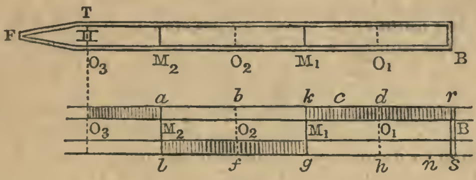

Fig. 9.

which O_3 and O_1 are the middle of dense portions, and b of a rare portion. This system corresponds to c'EsMcB in the figure referred to. Also let the lower system $O_2 s$, in which O_3 and O_2 are at the middle of rare waves, denote the reflected system. Now when any point c of the advancing dense wave kr reaches O_1, the corresponding point n of the returning rare wave will also reach it, and their differences of densities from the mean being equal and opposite in kind, the density at O_1 will be rendered of the medium density, which will be the permanent condition of the point O_1. The same can be similarly

proved of the points $O_2 O_3$ .... Again, at the point M_1, corresponding points of *similar* half waves—that is, both dense or both rare—always meet; and therefore at one time the excess of density will be doubled there, at another time the defect of density. The point M will therefore be of continually varying density, whose limits will extend twice as much above and below the mean as those of the original wave; but the two meeting waves lying in opposite directions, the tendencies of their corresponding points to produce motion when they meet at M, will be equal and opposite, and therefore the particles of air have at this point no *horizontal* motion. The same things can be proved of the similar points $M_2 M_3$, &c.

46. The mouth of the pipe O_3 must be one of the nodes, because, from its communicating with the external air, there can be no excess or deficiency of density there as at the loops. This is proved by experiment; for by cutting the tube entirely round at any node, such as O_1, and separating the parts to a minute distance, the pipe continues to produce the same sound. The point O_1 might thus be made the mouth of a closed organ-pipe of the length $O_1 B$; and by exciting in it a wave, one extremity of whose dense portion would just reach O_1 after reflection at B, while its other extremity is entering at the mouth, a stationary undulation could be kept up. Hence it appears that the longest complete wave that can produce a stationary undulation in a closed organ-pipe, is 4 times the length of the latter. Since sound moves 1125 feet in a second, the number of waves propagated in a second through such a pipe would be 1125 divided by 4 times the length of the pipe. The longest wave corresponds to the lowest or gravest note that the pipe is capable of producing.

47. Example.—In a closed organ-pipe $6\frac{1}{4}$ feet long, what is the number of complete vibrations produced in a second corresponding to its gravest or fundamental note? Ans. 45.

48. If the mouth of the organ-pipe is at the second node O_2, its length will be 3 times greater than before; but the number of vibrations is the same, and the length of the wave is $\frac{4}{3}$ that of the pipe. The waves in this case belong to the third harmonic of the fundamental note of the pipe $O_2 B$; for its gravest note would be produced by a wave 4 times its length, whereas the wave just considered is only $\frac{4}{3}$ of its length; and the number of vibrations produced by the fundamental note is to that of the other as 1 to 3. So if $O_3 B$ were the length of the pipe, the length of the first-mentioned wave would be $\frac{4}{5}$ths that of the pipe, and it would produce the fifth harmonic. In this way it appears that if the number of vibrations produced by a closed organ-pipe, when it sounds its

gravest note, be denoted by 1, the vibrations of the whole series of notes that it is capable of producing are represented by the series of *odd* numbers—

1, 3, 5, 7, 9, ... and so on.

A closed organ-pipe, therefore, cannot produce any of the even harmonics; and this result is conformable to experiment. The different notes are excited in an organ-pipe by the regulation of the blast; the gravest requiring a very moderate current of air compared with the harmonics.

49. In the open organ-pipe there is a mouthpiece at one end, and a stationary undulation can be excited in it, similar to that of the closed pipe, with this difference, that the open end in the open pipe is a node, and the closed end of the other a loop.

50. Let TB be an open pipe, and let a stationary undulation be excited in it such that $O_1 O_2 O_3$ shall be nodes, and $M_3 M_2$

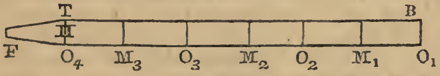

Fig. 10.

loops. The ends O_1 and O_4 are as if in direct communication with the atmosphere, and their uniform density is not disturbed. Since O_2 is a node, the pipe can be cut through there without altering the tone (article 46); and therefore a stationary undulation, consisting of waves of the length $O_1 O_3$ may be formed in an open pipe equal in length to $O_1 O_2$; but those waves are the longest that can thus be formed. Hence the gravest note that an open pipe of the length $O_1 O_2$ can yield, is produced by a wave of *double* the length of the pipe.

51. Were the pipe the length of $O_1 O_3$, a stationary undulation, formed by waves of the same length, could exist in it; but as the wave producing the fundamental note of this pipe would be double the length of $O_1 O_3$, the former undulation would give the second harmonic of the pipe $O_1 O_2$.

52. Again, a pipe of the length $O_1 O_4$ would be capable of producing a stationary undulation with a wave twice the length of $O_1 O_2$; but its fundamental note would be formed by a wave twice its own length, or six times the length of the half wave $O_1 O_2$; the latter wave, therefore, would give the third harmonic of the pipe $O_1 O_4$.

53. Thus it appears that the half wave producing the *fundamental* note of a pipe is *once* its length; that forming its *second* harmonic is ½ its length; that forming its *third* har-

monic is $\frac{1}{3}$ of its length; so those forming its *fourth*, *fifth* .... harmonics would be $\frac{1}{4}$, $\frac{1}{5}$ .... its length; hence, for the same open pipe, the number of vibrations producing the fundamental note being denoted by 1, the whole series of notes that the pipe is capable of producing will be expressed by

1, 2, 3, 4, 5, ... and so on.

An open organ-pipe, therefore, can produce the corresponding fundamental note, and the whole series of harmonics. In practice, however, not more than four or five can be easily produced.

REED-PIPES.

54. When sound is produced by means of a reed inserted into the end of a pipe, the pitch of the notes is determined in a manner different from an ordinary pipe. The *reed* is a small pipe of thin elastic materials, split along the middle to a certain length, so as to vibrate with the required degree of rapidity; or it may be a small pipe with an elastic plate, called a *tongue*, fixed in one side to cover exactly an opening in it. When air is blown through the reed, the sides of the former kind and the tongue of the latter vibrate, and the sound produced will evidently be determined by the number of vibrations in a given time. When the blast is increased, the rapidity of the vibrations also increase in a small degree. When a pipe is attached to the reed, the note will be different, but not that corresponding to the length of the pipe; although the vibrations of the tongue are sensibly influenced by those of the enclosed column of air in the tube. When the relative sizes of the attached pipe and reed are beyond certain limits, the vibrations of the air in the pipe modify those of the reed, or *predominate* over them; and by a proportion in the opposite extreme, the vibrations of the latter predominate over those of the former.

55. When the blast is very much increased in the first arrangement, some of the harmonics of the fundamental note are produced as in ordinary pipes. In the second arrangement, the note becomes more acute by an increased blast. Between these opposite relations there is a medium wherein there is no sensible predominance of either set of vibrations, and where the note is invariable for any strength of the blast; so that with a pipe so adjusted, any required degree of swelling can be given to the note without altering its pitch—a property that does not belong to the common organ-pipe. Weber first thought of determining the proper relation of the pipe and reed necessary to produce an invariable note; and by instituting the necessary experiments, he succeeded in his object.

56. The ingenious application of the reed to organ-pipes was perhaps suggested by the practice of children, who are in the habit of making reeds of both kinds by sedge, marsh-reeds, and corn-stalks.

INTERFERENCE OF SOUNDS.

57. When two aërial undulations, consisting of equal waves, meet in opposite phases—that is, the dense portion of one of the waves encountering the rare portion of another—the result is a medium density, and consequently no wave at the point of concourse; and if the waves are both sonorous, or separately capable of producing sound, there would thus be caused an entire cessation of sound, should the undulations reach the ear at the point of their interference.

58. If, however, the waves are of unequal length, they will interfere only at regular intervals, when the densest part of the one coincides with the rarest part of the other; and the resulting cessation of sound will therefore be only momentary and periodical. The effect of these interferences is to produce a peculiar interrupted sound similar to the repetition of the word *who-ah*, provided the interferences do not recur too quick or too slow. This acoustic phenomenon is called a *beat;* these beats are often so slow, that they can be easily counted; and at other times so rapid, as to produce the effect of a very discordant note.

59. If, for instance, two sounds from two different strings produce respectively 100 and 101 complete vibrations in a second, then as the lengths of their waves are inversely as the numbers of the vibrations, they will be unequal; 101 of the shorter waves will be exactly equal in length to 100 of the longer; and therefore, at some particular instant of time, the densest part of a wave of one of the undulations will reach the ear at the same time as the rarest part of some wave of the other, and consequently there will be a cessation of sound, which will, however, be only momentary, for in half a second after, the densest parts of two waves will reach the ear together, and produce a louder sound than either of the strings separately; and at the end of a second after the first instant of interference, 100 of the longer, and 101 of the shorter waves, will have reached the ear, and the two waves now meeting at it, are again in an interfering condition, and cause a momentary cessation of sound. In like manner, if two sounds produced respectively 40 and 41 vibrations in a quarter of a second, the beats would recur four times every second; and so on.

METHOD OF ESTIMATING THE NUMBER OF VIBRATIONS.

60. The number of vibrations in any note may be determined in the following manner:—Take an elastic string, and keep it tense by a given weight, and let it be so long, that its vibrations will be slow enough to be seen distinctly, and counted, which can be done by observing how many there are in 20 or 30 seconds; then, by means of a bridge, shorten the string till it produce a known note, ascertained by the aid of a well-tuned musical instrument; then the part of the string will be to the whole length as the number of vibrations of the latter in a second to that of the former.

61. When air is put into a state of uniform undulation, it is capable of communicating vibrations in a sensible degree to any elastic body capable of sounding isochronously with it; therefore when a note is sounded on one instrument, any other musical instrument near it will have those parts of it put in vibration that are capable of producing the same note: these are called *sympathetic undulations.* Thus, when a note is sounded on a flute with sufficient loudness, a string of a violin, or of a pianoforte capable of producing the same note, is instantly put into a state of vibration strong enough to produce an audible note; this appears to take place instantly, though in all probability 20, or 30, or 100 vibrations of the air must strike the string before its sound becomes sensible. A tumbler will sometimes be heard to sound loudly in sympathetic unison with a strong flute note. If two strings are tuned in unison on an Æolian harp, and one of them is made to sound, the other will immediately sound in unison; when the two strings are only nearly in unison, they strengthen each other's vibrations for a short time, till they reach a maximum, and then gradually weaken each other till the sound is nearly destroyed, when again they conspire to corroborate each other's vibrations; and so on, periodically, affording an illustration of the principle of interference.

REFLEXION OF SOUND.

62. When a progressive wave in its course meets with the surface of a solid body, its direct motion is stopped, and it returns, according to the same law of reflexion, as elastic balls, heat, and light; so that when a series of circular waves, diverging from a centre, meets a plane surface, the reflected waves have the very same form as if they diverged from a point on the other side of the reflecting surface, directly opposite to the origin of the waves, and equally distant from the surface.

63. A straight line drawn from the origin or primary centre of a wave to any point in its surface is called a *ray of undulation*, or an *undulatory ray;* thus, OC, OF are undulatory rays of the wave DCG.

64. Let O be the origin of undulation, SR the reflecting plane, O′ the point equidistant with O from the plane, and

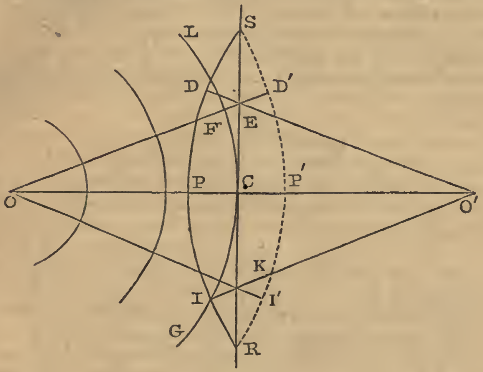

Fig. 11.

directly opposite to O, so that OO′ is perpendicular to RS; and let the wave DCG just reach the plane in C, any ray, as OF, when it reaches E, will be reflected in the direction ED, making the same angle with ES that OE does with EC; so that if O′E be joined, O′ED will be a straight line. But the velocity of the reflected wave being the same as that of the direct wave, while the ray OE would move from E to D′, the reflected ray will move from E to D, making ED equal to ED′. If, now, from the centres O and O′, circles SP′R, SPR be described with the respective radii OD′, O′D, while the direct ray would move from C to P′, the reflected ray would go from C to P; so while the ray OK would move directly from K to I′, when reflected it would move from K to I in the same time. Thus, every point of the reflected wave is now found to lie in the circular arc DPI, having O′ for its centre. The point O′, therefore, is analogous to an imaginary or conjugate focus.

65. When the origin O is far distant from the reflecting plane, the waves will be for some extent apparently rectilinear, being arcs of large circles. When the sea or any surface of water is bounded by a straight rocky shore or wall, if the

direct waves impinge on the shore obliquely, the reflected waves will be sent off also in an oblique direction, each ray making the angle of reflexion equal to the angle of incidence; and the reflected thus crossing the direct system of waves, will form beautifully-reticulated or chequered figures on the surface of the water. The rays of sonorous waves being reflected in exactly the same manner as those of water and light, exactly analogous effects will ensue. The following are some of the remarkable results of the reflexion of rays:—

66. Let O, O′ be the two foci of a shallow flat vessel ACBD of an elliptic form; let the vessel have a thin stratum

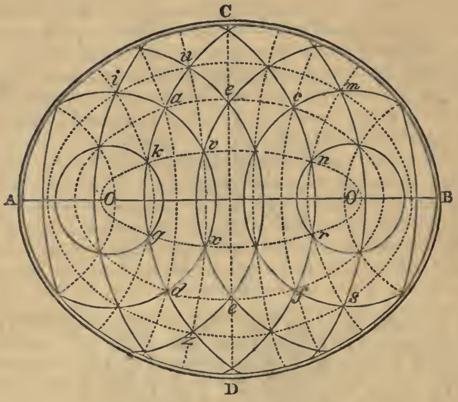

Fig. 12.

of mercury poured into it, then if any agitation be produced at one focus O, the direct series of waves proceeding from it will be reflected at the sides, and will converge towards the other focus; there will thus be excited two similar systems of undulations, which will exhibit the lines of interference arranged in elliptic and hyperbolic curves.

RESONANCE.

67. When the air is put into a state of sonorous vibration by any means, as by a note sounded on a musical instrument, it puts every elastic body into a similar state of vibration. The sounding-board of a pianoforte, for instance, is put into such a

state of vibration by sounding any note on it, that its simultaneous vibrations increase those of the air, and the original note is sensibly strengthened in intensity by the resonance. Even when several notes are sounding together, the sounding-board is put into a state of complex vibration by the simultaneous existence of different vibrations corresponding to the several co-existent notes. So, when the handle of a tuning-fork is placed on a table, the table serves as a sounding-board, and the resonance is very clearly heard, and serves to make the note distinct after it has otherwise become inaudible. If a sound be produced over the mouth of any vessel or cavity, not too wide in proportion to its depth, a certain degree of resonance will be sensible; and if the note corresponds with the vibrations of the internal air, the intensity is much increased by the resonance. From the same cause it happens that when a note is sounded in any room, it immediately produces the same note and its harmonics on any musical instrument in the room, such as a violin, a piano, an organ, or even a tumbler whose note is in unison with the former.

68. The structure of musical instruments in general illustrates this principle of resonance. The effect of a vibrating string by itself would be very feeble; but when it is stretched upon a massive wooden instrument, it communicates vibrations to the whole of that mass, and thus gives birth to a powerful and voluminous sound. In the violin and pianoforte, the body of the instrument constitutes the sonorous substance whose vibrations act upon the surrounding air: the strings are partly the medium through which the instrument is struck, and partly the regulators of the sounds. If the body of a violin were struck by a sharp blow, it would vibrate and sound according to its own natural tendency; that is, the pitch of the sound would depend upon the size, shape, and material of the instrument, exactly as in the case of a tuning-fork or a bell: but when, instead of applying the stroke direct, we set the instrument a vibrating by means of one of the strings, the vibrations of the mass are completely controlled by those of the string, and the resulting sound is therefore a voluminous expansion of the note determined by the string's vibrations. In place of a thin piece of wire or catgut, the air is acted on by an extensive mass of wood, and the result is proportionally great.

69. The sound of the human voice is dependant on the resonance of the bony mass of the skull. The effect of the vocal strings sounding by themselves is observed in a *whisper*. But when true voice is produced, it is by the vibrations of the vocal chords being communicated to the solid mass of the

head, exactly as the vibrations of the violin-strings are communicated to the entire body of the instrument. Hence the power and character of a person's voice depend on the size, form, and texture of the skull, to the same extent as the fineness of a violin or pianoforte is regulated by the wooden part of their structure. The feeble screech of the infant voice arises from there being as yet no bony matter in its head; but according as the ossification of the skull proceeds, the voice becomes firmer and stronger.

70. Sound may be conducted by means of rods of wood, or metal, or wires, from an instrument or from a sounding-board, to a sounding-board at a considerable distance; and in this way the combined harmony of an orchestra may be transmitted from the sounding-board that is influenced by the whole of the instruments to another at a distance, and be distinctly heard by an ear placed close to the second board; all the varieties of cadences and peculiar qualities of the sounds of the various instruments being distinctly preserved.

REFRACTION OF SOUND.

71. When sounds pass from one medium into another, they are refracted, and, in consequence, they suffer a considerable dispersion in passing through various media of unequal elasticities. At a certain angle of medium, in passing from a more to a less elastic medium, sound, like light, suffers a total reflexion.

ECHO.

72. When waves of sound impinge directly—that is, perpendicularly on a plane—they are reflected also perpendicularly; and if a person is standing at the origin of the sonorous waves, the reflected will be nearly as strong as the original sound, unless the plane be far distant, in which case it will be weakened. Since, however, when 10 single sounds succeed each other in a second, they form one continuous sound, and as sound moves over 112 feet in the tenth of a second, any single sound from a distance must precede another by at least 112 feet, in order that the latter may not be blended or confounded with the former, or may appear a distinct sound. Since the reflected waves in the case of an echo have to return over the same path as that passed over by the direct sound, a reflecting surface must be distant from the observer at least the half of 112—that is, 56 feet—in order that a distinct echo be heard; though at a less distance a species of resonance is audible, arising from the sound and echo forming one conti-

nuous sound, though of short duration when the sound is single or momentary.

73. The distance of the reflecting surface that causes an echo, can easily be computed from the known velocity of sound, when the interval of time between the sound and echo are known; or, conversely, the interval can be computed when the distance is known. The interval of time that elapses between the instant of the emission of a sound at any place, and the return of the echo to the same place, is evidently just double the time required for the transmission of sound from the place to the reflecting surface.

74. Example 1.—The distance from an observer of a rock that gives an echo is 400 yards; what is the interval between the sound and the echo?

The sound must move over twice 400 yards during the interval, or 2400 feet; and this number, divided by 1125, gives $2\frac{1}{7}$ seconds nearly for the interval required.

75. Example 2.—A rock whose distance is unknown, causes an echo at an interval of $1\frac{2}{3}$ seconds after the sound; what is its distance?

The distance is that corresponding to half this time, or half the distance due to the whole interval. Now, 1125, multiplied by $1\frac{2}{3}$, gives 1875 feet, or 625 yards, and the half of this, or 312 yards, is the required distance of the rock.

76. When the observer is situated at or near the centre of a circular surface—as at the centre of the arch of a bridge, or of a circular apartment, or of a hollow in a rock of the form of an upright cylinder—the echo is then much stronger than when the reflecting surface is plane; for the reflected waves in such cases all converge towards the place of the observer, just as light incident on a concave mirror, when the radiant point is in its centre, would all be reflected towards the centre. Whatever be the form of the surface, if the observer be situated at its centre of curvature—that is, the centre of the circle or sphere most nearly coinciding with the reflecting portion of it—the waves will be reflected from it so as to converge towards the place of the observer.

77. But it is not necessary, for the production of an echo, that the origin of the sound should be at the place of the observer; the origin of sound, the place of observation, and the reflecting surface, may be situated anywhere, provided they are not too far distant. For when the reflecting surface is of an elliptic form, and the origin of waves in one focus, the reflected waves converge towards the other focus, and consequently if the observer is placed there, he will hear the re-

flected sound after hearing the direct sound, the latter passing over a shorter path than the former; and if the difference of the paths of the direct and reflected waves exceeds 56 feet, a distinct echo will be heard; but if less than this, there would be only a continuous sound of somewhat longer duration. As any portion of a concave curved surface very nearly coincides with some elliptic, or rather spheroidal, surface, if the origin of the sound and the observer be in the two foci, the reflected sound will converge towards the observer, and will be louder than if it were reflected from a plane surface. But diverging waves reflected from a convex surface would produce a weaker echo than a plane surface, because the waves would, by the reflexion, be made still more divergent than the incident waves.

78. From these principles, it is evident that the echo from a distant rock may be louder than that from one nearer, if the latter be plane, and the reflecting portion of the former nearly circular or spherical, the centre being at the origin of sound.

79. When an apartment is of a circular form, or of the form of a regular polygon—that is, octagonal or hexagonal, &c.—and the origin of sound is near the wall, an observer situated close by any other side of the apartment will hear the reflected sound much better than the direct sound. In this case, as in elliptic surfaces, the quantity of direct undulatory rays that reach the observer's ear is very small compared with that of the reflected rays; and on this account two persons situated in the foci could converse, and yet be inaudible to a company at any place between them.

80. On this principle is explained the phenomenon of whispering galleries, as that around the base of the dome of St Paul's cathedral in London, the elliptic cupola in the baptistry of the church of Pisa, the whispering gallery in the cathedral of Gloucester, and others. That of St Paul's is a well-known curiosity: it is 140 yards in circumference, and is just below the dome, which is 430 feet in circumference. A stone seat runs round the gallery along the front of the wall. On the side directly opposite the door by which visitors enter, several yards of the seat are covered with matting, on which the visitor being seated, the man who shows the gallery whispers with the mouth near the wall, at the distance of 140 feet from the visitor, who hears his words in a loud voice, seemingly at his ear. The mere shutting of the door produces a sound like a peal of thunder rolling among the mountains. The effect is not so perfect if the visitor sits down half way between the door and matted seat, and much less if he stands near the man who speaks, but on the other side of the door.

81. There are many famous *natural echoes* to be met with, that repeat two, three, four, five, six, or many times. One of the most remarkable natural echoes is that heard on the banks of the Rhine at Lurley-Fels. If, in favourable weather, a musket be fired on one side, its report is reflected from crag to crag, and is thus alternately repeated on opposite sides, as represented in the subjoined figure. P is the origin of the

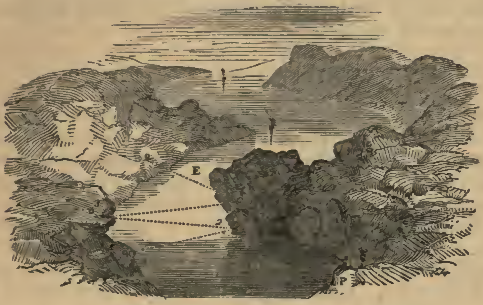

Fig. 13.

sound, the rays of which crossing the river, strike the crag at 1, and are then reflected to the crag 2, next to 3, and so on to subsequent points, till it dies faintly away, or finally ceases opposite E, after seventeen repetitions.

82. There is an echo at Aldernach, in Bohemia, that repeats seven syllables thrice. In ancient times there was a famous echo known at Capo-di-Bove, and at the Villa Simonetta, near Milan, the latter of which repeated thirty times; as did also another in a building in Pavia. There was said to be an echo in the tomb of the Metelli in ancient Rome that repeated eight times distinctly the first verse of the "Æneid," which is a hexameter line consisting of fifteen syllables. It is obvious that the tomb must have been of great length, to cause an echo with so long an interval as was necessary for pronouncing a whole hexameter line articulately, which would require at least two seconds, corresponding to an echo caused by a reflecting surface 375 yards, or 1125 feet distant. One of the most singular echoes known is that described by Barthius, situated on the Nahe, near Bingen, not far from Coblentz, which repeated seventeen times the sound. About this echo there are several peculiarities besides: the voice is indistinctly heard, but the echo is very clearly audible, and

in surprising variety. A tower at Cyzicus repeated seven times; at Brussels an echo responded fifteen times; one at Thornby Castle, Gloucestershire, repeats ten times distinctly; one on the north side of Shipley Church, in Sussex, repeats twenty-one syllables; one in Woodstock Park, mentioned by Dr Plot, repeats seventeen syllables by day, and twenty by night. White records an echo near Selborne, in the king's field in the path to Norehill, which repeated ten syllables, and the last as distinctly as the first, if quick dactyls were chosen; as, for example—

"Tityre tu patulae recubans."

The reverberation took place from a stone building at a distance of 258 yards. Some time after its discovery, a hedge planted for the protection of a hop-garden obstructed the voice of the speaker, and silenced the response. In the centre of Königsplatz, at Cassel, where six streets meet in a large oval, there is an echo which is said to repeat six times distinctly. An echo at Roseneath, near Glasgow, described by Dr Birch, but now lost, repeated three times a tune played with a trumpet. Near to Samson's Ribs, near Arthur Seat, Edinburgh, there is a good echo, where from the foot of an isolated rock the voice is distinctly returned by a southern wall. The echo of Westminster Bridge is said to be heard in the arch-roofed sitting-places, from the dry arches below, and *vice versâ*. Sir John Herschel has noticed a remarkable echo at the Menai Bridge, which he describes: the percussion of a hammer upon one of the main piers is successively returned by each cross-beam which supports the roadway, and from the opposite pier, distant 576 feet; and in addition, the sound is often repeated between the water and the bridge. In an Irish grotto near Castle Comer, in Kilkenny—a fit locality for such a witch-like sound—at a distance of eighteen feet from the inmost recesses of the cavern, an echo falls upon the ear. One of the most delightful echoes in the sister kingdom is met with in the Bay of Glena, on the side of the lower Lake of Kilkenny, called the "eagle's nest:" it sends forth the percussion of a fowlingpiece like the voice of thunder bellowing among the lofty reeks of Kerry. At Paisley there is a fine echo in the burying-place of Lord Paisley, Marquis of Abercorn: musical notes rise softly, and swell till the several echoes have reverberated the sound, and then they die away in gentle cadence. The caves of Torridon, between Applecross and Gairloch, on the north-west coast of Scotland, possess singular echoes, subject to extinction by atmospheric influence. That

from the old castle of Lochaneilan, Inverness-shire, is a good echo. Southwell describes a remarkable one, which is probably that at the Marquis Simonetta's villa near Milan, which repeats the *vox humana* above forty times, and the report of a pistol about twenty times more: it is in the morning and evening that the effect is most apparent. Hundreds of other instances—differing according to locality, state of atmosphere, temperature, &c.—might be recorded.

83. When an echo is produced by a concave surface of sufficient extent, or by several surfaces that cause the waves to converge towards one place, this remarkable effect sometimes happens—namely, that the echo is decidedly stronger than the original sound heard directly without reflexion at the same distance; or, in other words, the echo is louder at the observer's place than the original sound is to a person standing at the reflecting surface when the origin of sound is at the former place. Thus the voice of a person calling aloud is with some difficulty heard at the distance of half a mile; whereas an echo is often very distinctly heard when caused by a surface a quarter of a mile distant, in which case also the waves pass through a distance of half a mile in their direct and reflected course.

84. Any instrument that is capable of producing or modifying sound may be called an *acoustic instrument.* Thus if a person speak through a cylindrical pipe—one of the simplest of acoustic instruments—it will be found that the sound emitted at its farther extremity, especially if it be of considerable length, has much more intensity there than if no such instrument were used. The greater intensity in this case obviously arises from the circumstance, that the sound is not weakened by being diffused all around, but that its strength is preserved by the repeated reflexions of the rays from the internal sides of the tube. As an experimental proof of this fact, Biot and Martin conversed in a whisper along an empty iron water-pipe in Paris at night, through a distance of 3000 feet; though, however, the perfect tranquillity of night was favourable to the experiment.

85. Although musical instruments are, properly speaking, acoustic, yet the former more specific term is generally used in reference to them. Of the ordinary acoustic instruments, none is more interesting or remarkable in its effects than the *speaking-trumpet.* Any tube used for strengthening the voice, and also for confining it to a particular direction, may be called a *speaking-tube*—as, for instance, the fixed tubes used in offices and warehouses for conveying information from one room or flat to another.

86. Although a cylindrical tube strengthens the voice very much, still the rays of sound being reflected from one side of it to the other, they must emerge from its extremity in directions inclined to the axis, and must therefore diverge considerably. The best form of the speaking-trumpet is a parabola, that has its length great compared to its breadth; for with this construction, if the focus of the parabola be in the middle of its narrow end, the voice being emitted there, will diverge in all directions within the tube, and after impinging on its sides, will be reflected like the rays of light, in directions that are all parallel to the axis, and in this course it will emerge from the further extremity; and consequently the sound will be more concentrated than by any other means.

87. Thus if the sides ceO, rnP (fig. 14) of a trumpet are parabolic, m being the focus at which the mouth is applied, the

rays of sound mc, me, mr, mn diverging from m to the sides of the tube, are reflected in the lines eu, cv, &c. parallel to the

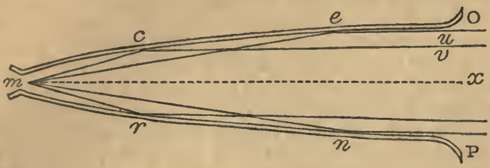

Fig. 14.

axis of the tube, with no sensible divergence; though in their progress through the tube they will be weakened by the lateral resistance of the air. The tube of course is supposed to be of the form that would be produced by the figure revolving about its axis mx, which would be a paraboloid.

88. Such is the force given to the voice by the speaking-trumpet, that Kircher, by means of it, about the end of the seventeenth century, read the Litany at a convent situated on the top of a hill, to a congregation of 1200 persons, who heard it at the distance of from two to five Italian miles. With a properly-constructed trumpet twenty feet long, a strong voice can be distinctly heard at sea at the distance of three miles.

89. An inverted speaking-trumpet forms a *hearing-trumpet;* the point m being applied to the external opening of the ear; but it is usually made of a small size, or from a few inches to a foot in length.

ACOUSTIC ARRANGEMENTS IN PUBLIC BUILDINGS.

90. Theatres, music-halls, churches, and lecture-rooms, ought to be constructed with reference to the acoustic effect of their various surfaces, in order that there may be no perceptible echo or resonance; for when these accompany the speaker's voice in any great degree, indistinctness and confusion of sound are the inevitable consequence. But, on the other hand, if there is no reflexion of the sound at all, and if the place is very large, the speaker's voice may be too weak to be distinctly heard. The best form for distinctness of sound would be that of the speaking-trumpet; but as this form is very inconvenient, and expensive to construct, only a distant approximation to it is practically attainable.

91. The interior of the building, therefore, when large, ought to be long compared with its breadth and height; for in this case the sound reflected from the side walls, and the

comparatively low ceiling, at small angles, would unite in strengthening the sound. In most cases the floor, when it is irregular, or has some soft covering, or when the building is filled with people, can have no sensible effect, except to absorb any direct or reflected sounds that may reach it. Generally speaking, that form of apartment is best suited for the proper distribution of sounds in which the length is from a third to a half more than the breadth, the height somewhat greater than the breadth, and having a ceiling bevelled off all round the sides, called technically a coved or *coach roof*, from its being lower at the sides than centre.

92. When a distinct echo is heard from the distant parts of a building, it can be stifled by suspending loosely on the wall any sort of cloth; or, in some cases, by hanging short curtains around the cornices; or merely by hanging small pieces of cloth from different parts of the side cornices, so as to project inwards a few feet towards the middle of the ceiling. When a building is crowded with people, they generally serve the same end as curtains and drapery in preventing echoes.

93. Confusion of sound is frequently occasioned by projections and recesses in the interior of the building. The former interrupt, and consequently weaken the sound; the latter cause a considerable resonance from the repeated reflexions, and an echo when they are of great extent. The confusion caused by an echo behind the chancel in a church has been corrected by merely erecting a concave parabolic surface behind the pulpit, so that the speaker might be in the focus; by which means the echo is partly interrupted, and the sound strengthened and more distinctly heard. The confusion caused by recesses like those in the transepts of a church, can scarcely be corrected by any means that do not at the same time weaken the sound so much as to make articulation inaudible.

MUSICAL SOUNDS.

94. Sounds excited by vibrations succeeding each other at irregular intervals of time, excite a disagreeable sensation in the ear. Such sounds are distinguished by various names in common language, according to their peculiar characters—as roar, rattle, hiss, buzz, crash, noise, and so on. When, however, the vibrations are isochronous, their regular periodicity produces an agreeable sonorous impression, and the sound is then called a *musical sound*.

95. Besides the quality of isochronism of the vibrations of a musical sound, another essential circumstance in its constitution is, that there should be at least 16 complete vibrations or waves, or 32 half vibrations in a second; and on the other hand, that the number of complete vibrations should not exceed 8192 in the same time. A less number of vibrations than the former, or a greater number than the latter, in a second, could not produce an audible note. When the vibrations, however, have a more than ordinary intensity, it is found that the limits of audibility are extended to notes caused by 8 and 16,384 complete vibrations respectively in a second.

96. That musical notes are produced by a rapid succession of aërial impulses at equal intervals, is very clearly illustrated by an instrument called the *syren*, the invention of Cogniard de la Tour. A blast of air is forced through a narrow aperture in a pipe, and a flat circular disk perforated near its circumference, with a number of small holes equidistant, and in a circle concentric with the disk, is so applied to the pipe, that the blast is interrupted by it, excepting when one of the holes in the disk is opposite to that in the pipe; and when the former is made to revolve rapidly, the resulting aërial impulses cause a series of isochronous vibrations that produce a musical note, and the corresponding number of its vibrations can very easily be computed, from knowing the number of holes and of revolutions of the plate. The results obtained by this instrument agree exactly with those found by other methods.

97. All the elastic bodies that are capable, by their vibrations, of producing sounds, may also be made to produce musical sounds of some quality or other. Musical strings, which are made of lamb-gut, steel and brass wires, elastic membranes, are capable, when under sufficient tension, of

producing musical vibrations, and also the columns of air in organ-pipes and other wind-instruments.

98. The notes that are caused by more than a medium number of vibrations belong to the shrill or high kind of notes, and are called *acute;* the others, that have fewer vibrations, are low or *grave* notes. The quality of a note that depends on its acuteness or gravity is called its *pitch;* the acute being of a high, and the grave of a low pitch. Besides the pitch, the character of musical notes comprehends also the properties of *quantity*, and what is specifically termed *quality.* The quantity depends on the extent of the vibrations, and is the same with strength, loudness, or intensity; and by quality is meant the peculiar property of musical sounds, whereby, when they are exactly equal in pitch and quantity, they are still distinguishable from each other; as the same note sounded equally loud on a trumpet and a flute. From its peculiar quality, the sound of the human voice is easily distinguishable from the sound of any artificial instrument of music, or from that of the most perfect speaking machine.

99. The note termed the middle C on the harpsichord is produced by nearly 256 vibrations in a second; hence, if this be the exact number to be assigned to that note, then its numerical expression or designation is 256. Now this number is just the 8th power of the number 2—that is, its continued product by itself repeated 8 times, or, as it is more concisely expressed, 2^8; hence, using the sign of equality (=), this value is expressed thus: $C = 256$, or $C = 2^8$.

100. The note produced by twice as many vibrations as another note, is called its next higher *octave;* thus the note whose vibrations are 512 in a second, is the octave of C, and is denoted by the subscript figure 1, or C_1; hence $C_1 = 512$, or $C_1 = 2^9$; for 512 is the continued product of 2 repeated 9 times. So a note produced by half as many vibrations as another, is called its next lower octave; thus C is the lower octave of C_1. The note that is an octave higher than C_1—that is, the octave of C_1 itself—is denoted by C_2, the next higher by C_3, and so on. So the note that is an octave lower than C is denoted by C_{-1}, and its number of vibrations is the half of 256, or 128; that is, $C_{-1} = 128$, or $= 2^7$. All the octaves of C, from the lowest to the highest, within the ordinary compass of the musical scale, are therefore represented, and their numerical values expressed thus:—

$C_{-3} = 32 = 2^5$	$C_1 = 512 = 2^9$
$C_{-2} = 64 = 2^6$	$C_2 = 1024 = 2^{10}$
$C_{-1} = 128 = 2^7$	$C_3 = 2048 = 2^{11}$
$C = 256 = 2^8$	$C_4 = 4096 = 2^{12}$

101. The length of the waves producing the note C_{-3}, is found by dividing the velocity of sound 1125 by 32; the result is 35 feet nearly, which is just the length of an open organ-pipe capable of sounding this note. The next note C_{-2} would of course be produced by a pipe of half the length, or $17\frac{1}{2}$ feet, and so on; and the highest note C_4 by a pipe $3\frac{1}{3}$ inches; and the middle C by a pipe $4\frac{3}{8}$ feet.

102. Any number of notes of an intermediate number of vibrations may be inserted between any two successive notes of the above series. The series included between two notes that are each other's higher and lower octaves respectively, including these notes, is called an *octave*. Whatever number of notes may be inserted in an octave, the same number may be inserted in the next higher octave, and the numbers of vibrations corresponding to the latter series of notes, would just be double of those producing the corresponding notes of the former octave; so that the numerical values of the notes in one octave would have the same relation to each other as those of any other. There is one particular series of notes that has been in almost universal use for centuries, to which, therefore, our attention must be chiefly confined. The number of notes between C and C_1 in this system is six, and with C and C_1 they constitute an octave. If the number of vibrations for the note C be denoted by 1 (which is, in fact, the number in the 256th part of a second), then those for the other notes, which are named D, E, F, G, A, and B, are as follow:—

$$C = 1,\ D = \tfrac{9}{8},\ E = \tfrac{5}{4},\ F = \tfrac{4}{3},\ G = \tfrac{3}{2},\ A = \tfrac{5}{3},\ B = \tfrac{15}{8},\ C_1 = 2.$$

Or giving C its proper value, 256, the values will then be—

$$C = 256,\ D = 288,\ E = 320,\ F = 341\tfrac{1}{3},\ G = 384,\ A = 426\tfrac{2}{3},\ B = 480, \text{ and } C_1 = 512.$$

103. Since the lengths of strings of the same kind, and under the same tension, are inversely as the number of vibrations in a given time, if the length of the string that gives the note C be denoted by 1, as 1 foot or 1 yard, or any other dimension, the lengths of the strings that would give the above series will be—

Name of Note.	C	D	E	F	G	A	B	C_1
Length of String.	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$

These numbers also denote the comparative lengths of the organ-pipes capable of sounding the corresponding notes.

If C_1, D_1, E_1, F_1, G_1, A_1, B_1, C_2, be substituted in the table, the numbers will require to be halved throughout; and so on for any number of octaves.

104. The above scale of notes has been named the *diatonic scale* or *key*. It will be afterwards seen that the numbers of vibrations of the notes in an octave on this scale have the simplest possible relations, which renders them well adapted for melody. Any note, as C, to which the succeeding notes forming an octave are referred, is called the *fundamental* note, the *tonic* or *key-note;* and the others in succession, the *second, third, fourth, fifth, sixth,* and *seventh.* Thus E is the third of C, G is its fifth, B is its seventh, and so on. The fifth is also termed the *dominant*, and the third the *mediant.* The notes immediately above and below the tonic and dominant are named by prefixing to them *sub* and *super;* thus—

Key-note.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Octave.
Tonic.	Super-tonic.	Me-diant.	Sub-domi-nant.	Domi-nant.	Super-domi-nant.	Sub-tonic.	Tonic.

105. The *interval* between any two successive notes of the scale is expressed by the ratio of their numbers of vibrations, and may be called a *scale-interval,* to distinguish it from other intervals. Thus the interval between C and D is expressed by the ratio of 1 to $\frac{9}{8}$—that is, by $\frac{8}{9}$; that between D and E by the ratio of $\frac{9}{8}$ to $\frac{5}{4}$—that is, by $\frac{9}{10}$; that from E to F by the ratio of $\frac{5}{4}$ to $\frac{4}{3}$—that is, $\frac{15}{16}$; and so on. The interval $\frac{8}{9}$ is called a *major tone;* $\frac{9}{10}$ a *minor tone;* and $\frac{15}{16}$ a *major semitone.* All the scale-intervals belong to one or other of these three denominations.

106. The interval between any two notes—called in general a *musical interval*—is measured in the same manner as the scale-intervals—that is, by the ratio of the numbers of vibrations corresponding to them, or of any other two numbers proportional to them, as those in the table in a former article. Thus the interval between the tonic and its fifth, called also a *fifth,* is the ratio of 1 and $\frac{3}{2}$—that is, $\frac{2}{3}$.

107. When any two notes are sounded together, the compound sound is called a *chord,* which is either agreeable or disagreeable to the ear; the former are called *perfect chords, concords,* or *consonances;* and the latter *imperfect chords, discords,* or *dissonances.* Thus all musical intervals whatever are divided into *concordant* and *discordant intervals.*

108. When any musical interval can be expressed by the

ratio of two numbers not exceeding 5, it is concordant; all others are discordant.

109. From the numerical value of a concordant interval as thus limited, it is evident that the two notes separated by such an interval will, if sounded together, produce at least one coincidence of their vibrations for every 5 of one of them, and for a number of the other, not exceeding 5 at most. Thus, for the tonic and dominant, the ratio or interval is $\frac{2}{3}$; so that at every second vibration of the former, and every third of the latter, there will be a coincidence; and the resulting chord, from its frequency, will be one of the most agreeable of the consonances. *Harmony* arises from the coexistence of concordant sounds, and consists of a succession of consonances.

110. The subjoined table shows the various intervals between the key-note and the other notes of the diatonic scale, the names of the notes, the ratios of the corresponding numbers of vibrations, and the ratio of the lengths of the strings or organ-pipes capable of producing them:—

Names of Notes.	Tonic.	Super-tonic.	Mediant.	Sub-domi-nant.	Domi-nant.	Super-domi-nant.	Sub-tonic.	Tonic.
	Key-note.	Second.	Third.	Fourth.	Fifth.	Sixth.	Seventh.	Octave.
Nos. of vibra-tions.	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2
Lengths of strings.	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
Intervals and their names.		$\frac{8}{9}$ Major tone.	$\frac{9}{10}$ Minor tone.	$\frac{15}{16}$ Major semitone.	$\frac{8}{9}$ Major tone.	$\frac{9}{10}$ Minor tone.	$\frac{8}{9}$ Major tone.	$\frac{15}{16}$ Major semitone.

111. That the agreeable or disagreeable quality of chords depends on the number of coincidences of vibrations, in reference to the whole number performed in a given time, may be shown by a reference to other well-known facts. The regular recurrence of any sensation not naturally disagreeable, produces an agreeable feeling. When two people are walking together, if the steps are made in the same time, the effect is agreeable; whereas if they do not keep the step, the irregularity in the movement produces a disagreeable feeling. If,

however, in the case of unequal movement, the coincidences are at every second of the slower step—that is, if two steps are made by one of the people, while the other makes three—the frequency of coincidences gives an idea of a periodic relation still simple, yet more complex than in the case of equal movement. The first case is analogous to that of two coexisting unisonal notes, or the case of *unison*, the most simple and perfect consonance; the latter is analogous to the chord of the key-note and its fifth. The dissonance of the chord of the key-note and its second is manifest from the fact, that 8 vibrations of one coincide with 9 of the other, so that there is only one coincidence for every 8 vibrations of the former; and on this unfrequency of coincidence, and consequent irregularity of relation, the discordant feeling depends. The same may be said of the chord of the key-note and its seventh, the number of vibrations in the same time being as 8 to 15, and of course there is a still greater discordance than in the preceding case.

112. Were the ratios of the numerical values of the successive notes equal, so would the intervals; but this is not the case, as the lowest line of numbers in the preceding table shows. If these intervals were equal, it would be found that there would be fewer consonants. It would be easy, however, to adjust the lengths of the strings so that these seven intervals would be equal; but though each note in the scale would, when sounded separately, be as agreeable as any other musical sound of nearly the same pitch, yet they could not be so effectively arranged in the production of *melody*, which consists of the succession of single sounds, each having an agreeable relation to those immediately preceding. There must be a species of harmonic relation between the impression of the note called the key-note and those preceding it, within an interval of time not sufficient to efface these impressions. In accordance with this view of melody, it may be remarked that the closing note of every measure in a piece of music is generally the key-note, to which the others, therefore, are subordinate, or related according to the diatonic scale. In melody, therefore, the relations of the notes must generally be of the consonant kind, and no notes must be admitted into the scale that would cause great discords, and very few even that would cause moderate discords. Hence the diatonic scale is preferable to one with equal intervals.

113. From the key-note to its third, as from C to E, is an interval termed a *major third*, and expressed by the ratio 1 to $\frac{5}{4}$; that is, $\frac{4}{5}$. The interval from C to G is called a *fifth*, and its value is $\frac{2}{3}$. There is an interval, not contained in the above

form of the diatonic scale, which is much used in music, and expressed by the fraction $\frac{5}{6}$; and as this fraction is a little greater than the major third $\frac{4}{5}$, this new interval is less than the preceding. The major third, multiplied by $\frac{25}{24}$, will produce this interval, which is, in consequence, called a *minor third;* and the multiplier inverted $\frac{24}{25}$, which is again the interval between these thirds, is termed a *minor semitone.*

114. When a note is made higher or lower by a minor semitone, it is said to be *sharpened* or *flattened* respectively. A note is sharpened or flattened by multiplying its value respectively by the fractions $\frac{25}{24}$ and $\frac{24}{25}$. A flattened note is represented by the mark $\flat$ affixed to it, and a sharpened one by $\sharp$. Thus, C being represented in value by 1, when sharpened, it becomes $C\sharp$, or $\frac{25}{24}$; and when flattened, $C\flat$, or $\frac{24}{25}$. So G sharp is $G\sharp$, or $\frac{3}{2} \times \frac{25}{24}$ or $\frac{25}{16}$, and G flat, or $G\flat$ is $\frac{3}{2} . \frac{24}{25}$ or $\frac{36}{25}$.

115. The minor semitone is the least interval used in music; any less interval is called a *comma*, though this is more specifically applied to the interval $\frac{80}{81}$. When the higher note forming an interval of a major tone is flattened, the interval is made less; but being nearer to the value of a major semitone than of a minor semitone, it receives the former name. Thus, when D is flattened by multiplying $\frac{9}{8}$ by $\frac{24}{25}$, the resultant note is $\frac{27}{25}$, or $D\flat$, and the interval between C and $D\flat$ is thus $\frac{25}{27}$, which differs from the major semitone $\frac{15}{16}$ by only a comma.

116. When the lowest note of the interval of a minor tone is sharpened, the reduced interval is still a major semitone. Thus, $D\sharp$ is $\frac{9}{8} \times \frac{25}{24}$ or $\frac{225}{192}$, and the ratio of $D\sharp$ to E is therefore $\frac{192}{225} : \frac{5}{4}$ or $\frac{15}{16}$, which is the semitone major. So if the lower note of a major tone be sharpened, the resulting reduced interval is $\frac{25}{27}$, which is reckoned a major semitone; and if the higher note of the interval of a major tone be flattened, the reduced interval is a major semitone. When a major semitone is multiplied by the fraction $\frac{128}{125}$, the product is the minor semitone, so that they differ only by a comma; consequently, since the intervals of the scale (excepting the semitones) are each composed of a major and a minor semitone, or of these and a comma, the sharp of one note can be taken as the flat of the next higher, and conversely. The great convenience resulting from this fact in the practice of music will be afterwards seen. At present, we have to consider what change must be made in the intervals of a scale of several octaves of permanent notes on a musical instrument, when some other note than C is assumed as the fundamental or key-note.

117. If eight strings AB, CD, EF, GH, &c. be taken of

any equal length, and if AB be stretched by a weight till it can sound a note which we may assume as a fundamental note, as, for instance, C; then if a bridge be fixed at a, at the distance

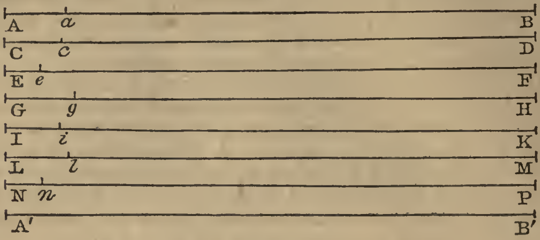

Fig. 15.

of $\frac{1}{9}$ of the length of the string from A, the remaining portion aB being $\frac{8}{9}$, will produce D; for C being denoted by 1, D will be denoted by $\frac{9}{8}$. If, now, the string CD, equal in length to AB, be made tense till its note is in unison with the note produced by aB, it will then of course sound D; and if a bridge be now placed at c, at a distance from C of $\frac{1}{10}$ of the length of CD, the remaining portion cD will sound E; for cD is $\frac{9}{10}$ of CD, and the ratio of the notes given by CD and cD is therefore $\frac{9}{10}$, which is the interval of D and E. So if the string EF be in unison with cD, and Ee be $\frac{1}{16}$ of EF, the part eF will give F. Next make GH in unison with eF, and place a bridge at g, so that Gg shall be $\frac{1}{9}$ of GH; make then IK in unison with gH, and take Ii $\frac{1}{10}$ of IK, and place a bridge at i; make LM in unison with iK, and let Ll be $\frac{1}{9}$ of LM, and then similarly make NP in unison with lM, and take Nn equal to $\frac{1}{16}$ of NP, and make A′B′ in unison with nP. The notes made by the eight strings in order will then be the octave C, D, E, F, G, A, B, C_1. The interval CD (that is, from C to D) is evidently the ratio of the length of aB to AB; the interval DE is the ratio of the length of cD to CD; of EF that of eF to EF; and so on. The portions Aa, Cc, Ee afford a tolerably good though not quite correct representation of the successive intervals, or of the major tone, the minor tone, and the major semitone. Were Ee only $\frac{1}{24}$ of EF, then the interval denoted by the ratio of eF to EF would then be only a minor semitone. The ratio of the length aB to AB gives the major tone; of cD to CD the minor tone; and of eF to EF the major semitone; and so on.

118. Suppose now that the scale is extended over a part of two octaves—

$$\begin{array}{ccccccccccccccccccccccc} C & & D & & E & & F & & G & & A & & B & & C_1 & & D_1 & & E_1 & & F_1 & & G_1 \\ & \frac{8}{9} & & \frac{9}{10} & & \frac{15}{16} & & \frac{8}{9} & & \frac{9}{10} & & \frac{8}{9} & & \frac{15}{16} & & \frac{8}{9} & & \frac{9}{10} & & \frac{15}{16} & & \frac{8}{9} & \end{array}$$

and instead of C being assumed as the key-note, that G is so. Then, according to the order of the intervals of the diatonic scale, there must first be two tones, then a semitone, next three tones, and then a semitone. Now, from G to A is a tone, but instead of being a major, it is a minor tone; the difference, however, between these tones is less than a comma, and they may be interchanged indifferently; the next interval, from A to B, is a tone, from B to C a semitone, from C to D and D to E are tones; but from E to F is only a semitone, whereas this interval (the sixth) ought to be a tone. Now this half-interval can be enlarged to a whole tone, either by flattening E or sharpening F; the former expedient is inadmissible, as it would change the interval DE to a semitone. Let F, then, be sharpened, and the interval EF♯ becomes a full tone; but the next (F♯ G) is now only a semitone, as it ought to be, being the seventh interval. When F is sharpened, then $\frac{15}{16} : \frac{25}{24}$ gives $\frac{9}{10}$; so that EF♯ is a minor tone. The interval F♯G is now $\frac{8}{9} : \frac{24}{25}$, or $\frac{25}{27}$, which is the same as $\frac{15}{16} \times \frac{80}{81}$; that is, it differs from the major semitone $\frac{15}{16}$ by only a comma, and is therefore admissible. The series of notes, then, for the key of G becomes

$$\begin{array}{ccccccccccccccccccccccccc} C & & D & & E & & F^\sharp & & G & & A & & B & & C_1 & & D_1 & & E_1 & & F^\sharp_1 & & G_1 & & A_1 \\ & \frac{8}{9} & & \frac{9}{10} & & \frac{9}{10} & & \frac{25}{27} & & \frac{9}{10} & & \frac{8}{9} & & \frac{15}{16} & & \frac{8}{9} & & \frac{9}{10} & & \frac{9}{10} & & \frac{25}{27} & & \frac{9}{10} & \end{array}$$

The key of G is therefore called the major key of G with one sharp. By assuming any other note as the key-note, it would be found that one or more of the notes would require to be sharpened or flattened in order to preserve the diatonic intervals.

119. Were it convenient to adjust all the notes of any musical instrument to any particular note assumed as the key-note, so that the intervals succeeding it would be the usual diatonic intervals in their proper order, then there would be no necessity for the sharpening or flattening of notes. But this adjustment would require very complex apparatus for most instruments, in order to alter the lengths of strings or pipes, and another method is therefore adopted, much more convenient, and sufficiently correct in practice, though not so in a theoretical point of view. The method is by employing a

clavier, as in the case of the pianoforte, giving not merely the notes of the key of C, called the *natural* key, but containing also stops for notes in the middle of the intervals of the major and minor tones; and since every minor tone consists of a minor and a major semitone, for any note denoted by 1 being sharpened, becomes $\frac{25}{24}$; and between this latter and the next note, at the distance of a minor tone from the first, the interval is $\frac{25}{24} : \frac{10}{9}$, or $\frac{16}{15}$; and as a major tone consists of a minor semitone, and the interval $\frac{25}{27}$ differing only by a comma from the major semitone, consequently the sharp of one note may be taken for the flat of the next higher, with only an error of a comma; or the error will be still less if the note interpolated in an interval of a major or minor tone be exactly in the middle of the interval, and then the octave would be composed of twelve semitones; namely—

C, C♯ or D♭, D, D♯ or E♭, E, F, F♯ or G♭, G, G♯ or A♭, A, A♯ or B♭, B, C_1.

But the adaptation is more uniform for all the notes, as key-notes, when the twelve half tones are made exactly equal. This plan causes more error for some keys, while, on the other hand, it causes less on others; but the extreme errors, which, however, are very small, are thus reduced.

120. This is the usual series of intervals on the piano, the organ, and all instruments with fixed notes. It makes what is called the *chromatic scale*, and from it the minor semitone is called the chromatic semitone. This scale is exceedingly convenient in *modulating*—that is, in changing from one key to another, though an experienced musical ear perceives in certain cases of modulation a sensible error in some of the notes—an imperfection arising from their fixity; whereas in the violin and similar instruments, modulations can be performed so as to satisfy the nicest ear.

121. If the lower note of the interval of a major tone, as C to D, be sharpened, the resulting note C♯ is at an interval of $\frac{24}{25}$ from C; and if the higher note D be flattened, it gives $\frac{25}{27}$; and the interval between C♯ and D♭ is nearly $\frac{32}{31}$, not differing much from a minor semitone. The interval CD would now be resolved into the three intervals—

C, C♯, D♭, D.

$\frac{24}{25}$ $\frac{31}{32}$ $\frac{25}{27}$

By interpolating in this way a flat and a sharp in every interval of a major or minor tone, and one intermediate note in the interval of the semitone, either the sharp of the lower, or the

flat of the higher note, there would thus be nineteen intervals very nearly equal in the whole octave; namely—

C, C♯, D♭, D, D♯, E♭, E, E♯ or F♭, F, F♯, G♭, G, G♯, A♭,
A, A♯, B♭, B, B♯ or C♭, C_1.

These nineteen intervals, if made equal upon a clavier of as many keys, would be very useful in the accurate tuning of some instruments in which this series of notes is introduced. Such a series is called the *enharmonic scale.* It was used and valued by the ancients, though from some cause it came into disuse; but it is certainly well adapted for accurate modulation, and may perhaps be yet appreciated. Recently, an organ, with 53 equal divisions in the octave, has been built; or with 9 intervals in a major, and 8 in a minor tone, and 5 in the diatonic semitone. Minute, however, as the intervals of the enharmonic scale are, they do not even approach to the almost indefinite number of imperceptible gradations of the voice in ordinary speech, which often form an apparently continuous cadence.

122. Of all concords, the unison is the most perfect, as C and C; the next is the key-note, and its higher or lower octave, as C and C_1, or C and C_{-1}; the next is perhaps a note, and its second higher or lower octave. Within the same octave, the key-note and its fifth is the most agreeable consonance; the next is the key-note and its fourth; and the next the key-note and its third. The third may be either a *major third,* consisting of two full tones, as the interval CE, or it may be a *minor third,* which consists of a tone and a diatonic semitone, as from D to F, or from A to C. These may be called *double* consonances, as they are caused by two coexistent notes. Of triple consonances in the same octave, any one note, its third and perfect fifth, make the best. The third may be either major or minor, but the fifth must be perfect—that is, it must be an interval composed of three tones and a major semitone. This triple concord is called the *common chord,* or the *harmonic triad,* either major or minor, according to the nature of its third.

123. It may appear remarkable that the double consonance CF of the key-note and its fourth should be so marked, and that the fourth is not admissible in a triad. The coincidences of the vibrations of C and F, or of 1 and $\frac{4}{3}$, take place for every 3 of the former and 4 of the latter; and for C and E, or 1 and $\frac{5}{4}$, they happen more seldom—namely, at every 4 vibrations of the former and 5 of the latter. Now compare the coincidences of the triad CEG with CFG. First, for C, E, and G, or 1,

$\frac{5}{4}$, and $\frac{3}{2}$; the least whole numbers that are proportional to these are 4, 5, and 6, so that the coincidences are at every 4 vibrations of the key-note, 5 of the third, and 6 of the fifth. Take now the triple chord C, F, G, or 1, $\frac{4}{3}$, and $\frac{3}{2}$; the least whole numbers proportional to these are 6, 8, and 9, so that the coincidences are only at every 6 vibrations of C, 8 of F, and 9 of G; the former, therefore, will be the more agreeable chord.

124. The diatonic scale has two forms or *modes*, according as it begins with C or A. In one mode, the third of the key-note is a *major* third; in the other, a *minor* third; and consequently the modes are accordingly denominated the *major* and *minor mode*. In the major mode, the interval of the third C E is major; and in the other, the third A C is minor.

125. In the minor scale, though the intervals are the same as in the major, the first is a full tone, the second a semitone. the third and fourth are tones, the fifth a semitone, and the sixth and seventh are tones. There is, however, this peculiarity in the minor scale, that in ascending from the seventh to the octave, the former note is made sharp, which of course makes the interval immediately below—that is, the last interval of this scale—a semitone, as in the major mode. The interval between the sixth and seventh would thus be increased to a tone and a-half. This sharp seventh is called the *accidental seventh* of the minor mode; it is called also the *leading* note, and is considered to be *essential* to the scale in ascending. This irregularity may, however, arise from a mere prejudice, on account of the habit of hearing the last interval of the major mode as only a semitone, the latter mode occurring much more frequently than the former.

TRANSPOSITION OF MUSICAL SCALES.

126. When an air is to be changed in pitch from one key to another, the alteration is called *transposition*. The flats and sharps, if there are any, are to be determined according to the method formerly mentioned in article 118. Thus, if it is required to write an air on the scale of F major; since the third interval from F—namely, that between A and B—ought to be a semitone, the B will have to be flattened, and then all the intervals will be the same as in the key of C, which is called the *natural key* of the major mode, and is the type of the major scale. For the same reason, the key of A is called the *natural key* of the minor mode. If it is required to transpose to the minor scale of D, for example, then since the fifth interval in the minor scale is a semitone, the fifth interval from

D must be a semitone; therefore B must be flattened. Accordingly, B♭ is the signature for this key.

127. Transposition is easily effected by means of a very simple instrument (which is new), consisting of two scales of pasteboard PN, MQ; or a scale of wood PN, with a slider MQ moving in a groove. On the principal scale, PN is the series of diatonic notes extending from C to G′, the major and minor tones being, however, made equal, and the semitones equal to the half of the tones, so that the series of intervals,

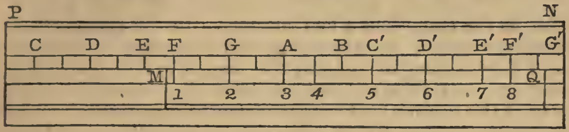

Fig. 16.

when the tones are halved, as represented in the figure, constitute the chromatic scale. On the slider MQ are the intervals for one octave, and by moving it till its first note (1) is opposite to the proposed key-note on the principal scale (suppose F), its divisions 2, 3, 4, 5, 6, 7, 8 will show what notes must be flattened or sharpened in the upper series of notes; for only the intervals in the latter series that do not coincide with those on the slider require to be changed. In the position of the scales in the figure, it appears that only B requires alteration; for if it were flattened, which would bring it to the position 4, the scales would coincide; the key of F, therefore, requires B to be flattened. For the minor scale, it is found in the same way that for the key of F the notes A, B, D, and E would require to be flattened. Were 1 put opposite to D, then it would be seen that the key of D major requires F and C to be sharpened; and that D minor requires only B to be flattened. Generally, it will be found, that since every major scale for any key-note, when its third and sixth are flattened by a chromatic semitone, becomes a minor scale for the same key-note, the latter scale will have three flats more or three sharps less than the former.

MUSICAL INSTRUMENTS.

128. The instruments or machines employed for producing musical sounds and their combinations are in modern times very numerous and varied, and great perfection has been attained in their construction. They may be classified in several

different ways; but the following considerations will assist in determining the groups that they most naturally fall into:—

129. In every musical instrument there are three things to be distinguished. These are, first, the *striking body*, or the means of setting the instrument a-vibrating; secondly, the *regulating medium*, which controls or determines the number of vibrations, and the pitch of the sound; thirdly, the *sounding mass*, or the body of the instrument, which acts upon the surrounding air, and through it to the ear of the listener.

130. The *striking body* may be a hammer of some solid material, as the clapper of a bell or gong. In the pianoforte, the strings are struck by a hammer with a surface of leather or felt. In the harp and guitar, the fingers are used to stretch the string, and then suddenly to let it go, whereby the elasticity of the material is brought violently into action. A rubbing surface is found very powerful in imparting the blow in the violin; this has the advantage of yielding a prolonged sound, besides giving the player a great command over the strength and quality of the tone. It is by the friction of the wet fingers that the beautiful sounds of musical glasses are kept up. The rubbing action is essentially a series of rapid and severe blows, of very small range individually, but in the aggregate possessing a very great degree of power. Friction is extremely energetic in acting upon the minute forces of cohesion and elasticity which bind the atoms of bodies into masses, as we see in its power of abrasion, and in its causing the evolution of heat, which never takes place without producing some atomic change in the structure where the heat is developed.

131. In one class of instruments an air-blast is the exciting cause of the sound; whence has arisen the designation of Wind Instruments. In some of these the blast is caused by the human lungs, and in others a bellows is made use of. The simplest form of wind instrument is the tube closed at one end, where the sound is produced by blowing at the mouth: a row of these, made of different lengths, forms what is called Pan's Pipes. In such a case, the air-blast from the mouth may be supposed to communicate a vibratory motion to the air within the tube, which, acting by friction on the solid mass of the tube itself, brings the whole into resonance, and yields the resulting sound. But the action may be explained differently; for it is not unlikely that the air-blast, acting on the sharp edge of the mouth of the pipe, creates at once the sonorous vibrations in the solid materials; and these vibrations will be governed by the size of the pipe. On this supposition, the air within the pipe will play merely a subordinate part, contributing only to the regulation of the note. In

several kinds of wind instruments, as in the common child's whistle, we are compelled to resort to this supposition of the excitement of sonorous vibrations by an air-blast properly directed on a sharp edge. Just as, in the musical glasses, the friction of the wet finger on the lip of the glass creates the sounding action, so the friction of a strong current of air upon the exposed edge of the whistle, or on the mouth of a Pan's pipe, can set the solid mass into the requisite state of vibration.

132. Reed Instruments are also wind instruments, the exciting cause in them being an air-blast. A reed has already been described as a thin slip of elastic substance, fixed at one end, and free to move at the other. If a rectangular opening is made in a brass plate, and if this opening is covered by an elastic slip of brass or steel, the slip may be made to vibrate by blowing against it with the mouth applied to the other side of the plate. A sound will be produced whose note will depend on the size and material of the slip, or on the rapidity of its natural vibrations. The intensity of the note will of course be increased by the resonance of the plate.

133. The clarionet is a wind and reed instrument, the reed being a slip of cane set in the mouthpiece, and vibrating to the player's blast. But when a reed is set in a pipe or tube in this way, its rapidity of vibration does not entirely depend on its own natural swing; for if that were the case, it would yield only one single note. The column of air vibrating within the tube controls the openings and shuttings of the reed, and therefore determines the note that it will communicate to the instrument by resonance. The vibrations of the reed itself, although reinforced by those of the air column, would have very little sonorous effect of themselves; but the flutter of the reed sets in action a similar set of vibrations in the mass of the pipe, and there are thus three separate vibrating masses all kept in unison by their mutual contact—the reed, the air, and the solid pipe—the last of the three being what gives to the sound its intensity and volume, or, we may say, its very existence as sound; for in all probability the pulses produced by the other two would be too feeble to reach the ear of a listener.

134. The organ-pipe is likewise a wind and reed instrument, with the parts somewhat differently arranged from the clarionet, but embodying the same essential principles. The air-blast is caused by a bellows, and the air, after entering the tube by the pedal, or opening at the lower end, passes along and escapes at the upper end by forcing open a tongue, thereby producing a series of vibrations, whose rapidity depends on the length of the tube—the vibrations of the enclosed air-

column being the means of regulating the tongue vibrations, and through them the audible vibrations of the mass of the pipe.

135. The *regulating medium* in musical instruments has been unavoidably noticed in the foregoing remarks upon the exciting cause or primary stroke. In stringed instruments, the vibrations of the string are determined by its length, thickness, and material; and when strings are stretched in a solid box, the resounding or communicated note of the box is governed by the natural note of the string. The box has no doubt a note natural to itself, which it would sound if struck directly; but this note, whatever it may be, is made to succumb to the note imparted from without, or to the regular series of tugs arising from the action of the string. We may easily suppose that the box would take in some sounds better than others; but in fact it is obliged to subordinate in its own natural note to the coerced note of the governing string. The strength of the player is exerted not merely to set the string in motion, but to keep up the additional thrill of the mass of the instrument.

136. In wind instruments, as already stated, the vibrating column of air is the regulating power. A column of air of a certain length has a fixed rate of vibration, and this rate is imparted to the tube that contains it, as well as to the tongues and reeds through which the tube is acted on. In the drum, the vibrations of the membrane are the regulating power, and these determine the rapidity of the acquired vibrations of the body of the instrument.

137. It thus appears that the *sounding material*, which is always the great mass or body of every kind of musical instrument, is in many cases forced to submit to a system of forced vibrations, and hence may be said to derive its merit from its readiness to take on any note that it is desired to impose. In the pitchfork, the bell, or the gong, which are struck directly, the note depends solely on the form and structure, and cannot be varied; the regulating medium and sounding mass are one and the same thing, and the resulting sound is that native to the instrument. But when a variety of notes has to be produced on one machine, the apparatus of a regulating power is superadded, and the plan of inducing foreign notes upon a sounding mass is resorted to. With this view, the form of the instrument needs to be very considerably modified.

138. In giving a short sketch of the principal musical instruments, it is convenient to commence with the simplest forms that are capable of yielding distinctive musical tones.

Of these, none can be simpler than a solid metallic *rod* suspended by a string, and struck by another piece of metal. A note is thus produced dependent on the size and material of the rod. The vibrations must be conceived as something analogous to those of an air-column of a limited length—that is, a series of condensations and rarefactions of particles will be passed from end to end backwards and forwards. But this class of longitudinal vibrations is not unlikely mixed up with others of a lateral kind; that is, the two ends of the rod may shake or vibrate while the other action is going on. Moreover, the stroke may produce also vibrations of twisting or torsion, and all the three sorts being coincident, a mixed sound will be the result. It is only in some one proportion of the dimensions of the rod that these three motions would yield the same note: hence it very rarely happens that a pure musical tone is produced from a metallic rod struck in this way. The only instrument in use that corresponds with this simple form is the *triangle*, which is a rod bent into a three-sided figure, and struck from side to side with another metallic rod; but the effect thus produced is not so much a set of musical tones as of rhythmical beats, which give time and emphasis to a march performance.

139. Next in simplicity to the rod is the *ring* or circle, whose principal vibrations, when struck, are in all probability a succession of flattenings and elongations of the circular figure. These may, however, be combined with lateral vibrations, and perhaps with those of torsion as well as with others propagated round and round. The want of a clear distinguishable note in this case is the proof that a complex sonorous action goes on, and that the different sounds are rarely in unison.

140. A third elementary form is the *plate*, or a plane surface of metal, glass, or wood, whose vibrations have been studied, in the manner already described, by using pieces of glass strewed with sand, and put in motion by a bow. This has shown that the mode of vibration is by opposite halfs or fractions of the plate vibrating in opposite directions, leaving a quiescent line of division. The effect of the *cymbals*, as compared with the *triangles*, gives us the means of judging the difference between the plate and the rod. The cymbals would appear to be not only more voluminous and powerful, but also more pure and simple in tone than the triangles.

141. The combination of these elementary forms in various ways gives rise to several well-known instruments. The *pitchfork* is a modification of the rod, and is so shaped, that the vibrations are chiefly of one kind—namely, the swing of the

legs backwards and forwards. Although it is impossible to extinguish entirely all other vibrations in favour of this one class, yet the lateral motion predominates so much, as to cause one distinct note to be discernible, which is the note belonging to the peculiar size and form of the instrument. The pitch-fork is formed to yield a particular note or pitch on the scale, and is hence employed as a standard of pitch in the tuning of instruments, or in starting off in a vocal air. The most familiar illustration of resonance, as already mentioned, is furnished by resting the fork on a table after it is struck. The whole mass of the table is in this way brought into unison with the note of the fork, and gives that voluminous expansion and exaggeration of tone which is the characteristic effect of resonance.

142. The *bell* may be looked upon as a combination of the tuning-fork with the circle. It is sufficiently massive to give a powerful tone without the aid of resonance from a superadded mass. Being struck with a metallic knob or clapper, it is set a-vibrating nearly on the principle of the ring—that is, by alternate flattenings and elongations. A bell can have no more than one note, determined by its size and dimensions; and the purity of the note must depend on the perfection of the form and proportions. The longitudinal vibrations of the pitchfork section must be in harmony with the vibrations of the circular sections, in order to produce an accordant tone. The bell is a very ancient instrument, and owes its extensive use to the powerful and piercing character of its sound. The large bells constructed for churches are often audible for miles; and the sound, which to a person close at hand is harsh and painful, becomes by distance soft and melodious.

143. The *gong* is a Chinese instrument of very great power, and its uses in China correspond to a great degree with the employment of the bell in other countries. Being of the shape of a tambourin, but made entirely of metal, it is a combination of the plate and circle. It is struck on the middle of the plate, and this part is sometimes swollen out into a spherical or round projection. The power and volume of the tone seem to the listener to be immensely greater than in proportion to the size of the instrument. But there would appear to be a very great advantage in this peculiar combination. The cymbals are an example of the power of the plate; they are, for their size, perhaps the most noisy apparatus that exists. And the rim or *cylinder* is seen in many ways to be a very advantageous form of instrument. In the tambourin and drum it is the resonant mass. It is, moreover, the type of the greater number of wind instruments. We are not to

wonder, therefore, at the effect that may be produced by a proper combination of so effective a pair of elements as the plate and cylinder. The noise and roar of a Chinese village on a festive day, when gongs are sounding in every direction, are such as to astonish and confound any foreigner that may happen to be present.

144. Both with the bell and the gong each instrument has but one note, and for a melody or tune there must be a series provided of different sizes, according to the desired range of notes.

145. The *musical glasses* are of the cylindrical form, and are excited into action by the friction of the wet fingers. The manner of their vibration is not very obvious. The tone arising from the rubbing of the edges is considerably different from the effect of striking the side in the manner of a bell, in which last case it may be supposed that the vibration is of the same character as in the bell and in the ring. Possibly, therefore, the internal movement of the particles, when under friction, is not the same as under a stroke; and it is not unlikely that the peculiar action may be an instance of *torsion*, which would correspond well enough with the nature of the sounding impulse.

146. The *drum* and *tambourin* have a greater alliance to the foregoing group than to any of the other principal divisions of musical instruments. A cylinder, with a tight membrane stretched over both ends, is the characteristic description of the drum. The chief power of the instrument resides in the resonance of the cylinder, which is put in motion by the vibrations of the membrane. If we suppose that a blow on the membrane draws together and contracts the circular edge of the drum all round, then there will be a corresponding expansion when the effect of the stroke ceases, and the circular edge will alternately contract and expand, and this will be the mode of the vibration. Doubtless these alternate contractions and expansions will be duly propagated from end to end of the cylinder, and the number of them will depend partly on the rate of vibration natural to the dimensions of the instrument, and partly on the rapidity of the stroke. Moreover, the air within and without the drum will be acted on by the direct impulses of the membrane, and the interior air may further affect the vibration of the solid cylinder. The double head is essential to the full tone of the drum.

147. This explanation, if at all near the truth, would indicate a different sonorous action in the drum from what we have assumed in the ring and bell under the agitation of the kind of blows communicated to them. If the effect of the

stroke on the drum-head be to bring together and contract the rim all round, this contraction being propagated from end to end, and regularly returned from the dumb end to the sounding one, the vibratory motion would be a sort of vermicular series of swellings and contractions, instead of the alternate flattenings and elongations that characterise the ring.

148. The drum, like the triangles and cymbals, is wanting in purity of tone, and is therefore incapable of contributing to the melody of musical choirs; and, like those, it is used to render prominent the *rhythm* or time of the composition, and to produce emphasis of effect in particular passages, there being musical compositions expressly adapted to bring out the power and efficacy of such accompaniments. As one part of the excitement arising from music is owing to this rhythmical effect, or the recurrence of beats at equal and regulated intervals, the instruments that excel in yielding the effect perform an important function, although they may be incapable of contributing to the stream of *melody*, which is a thing of a totally different nature, acting upon a distinct susceptibility of the human constitution.

149. The *tambourin* cannot be considered as specifically different from the drum. The agitation of the stretched membrane by the hand is the cause of the sound, and the effect is reinforced by the resonance of the solid rim and the rattle of the brass rings. Being a light and easily-handled instrument, it excels even the drum in rhythmical effect, and is the accompaniment of dance, and frolic, and gesture of the gayest and wildest description. In the frantic exhibitions of bacchanalian orgies and ecstatic worship, the tambourin and cymbals are appropriate instruments, being capable of leading to the highest pitch the intoxication and frenzy of rhythmical movements. The interposition of melody on such occasions would be quieting and soothing; hence the clangour and noise of the unmelodious instruments of maddening iteration were the source of the inspiring effect. In ballet music, the instruments of rhythm and emphasis are likewise indispensable.

150. After having adverted to the musical instruments of a more simple kind, we must now proceed to notice those of a complex description. The two great classes of instruments capable of yielding an extensive range of musical sounds, and of performing melodious compositions, are designated *stringed* and *wind* instruments respectively.

151. The principles regulating the sounds of strings have already been explained, and we have farther explained the influence of the appended solid mass in increasing the sound

by multiplication or resonance. The least complicated stringed apparatus is exemplified in the *harp* and in the ancient *lyre.* A series of strings, of different size, quality, and length, are stretched in a solid framework, each being adapted to produce a separate note, and the series forming a continuous scale. On being struck by the fingers, they sound their several notes, and melodies may be played by touching the proper strings in due succession. Also, by the use of two, three, or more fingers, contemporaneous tones may be sounded, and harmony superadded to the melody. The ancient lyre had very few notes; but the harp, as now constructed, is a large instrument, with notes extending over a wide compass.

152. The *guitar* is in principle the same as the harp and lyre, but it embodies the innovation of artificially shortening the strings, so as to bring more than one note out of each, which is done also in the violin. In this way, from a small number of strings a great number of notes may be produced, and the compass of the instrument is enlarged, while its dimensions remain the same. To suit this arrangement, the strings are chosen of such an amount of inequality, that an interval of (say) a fifth occurs between each adjoining pair, and the intermediate notes are formed by shortening the graver of the two by the fingers of the left hand.

153. In the harp and guitar, which are sounded by the fingers stretching and then suddenly letting go the strings, although melody may be derived in a very high degree, yet the sharpness and brevity of the tones are such as to make the beat and rhythm prominent. Hence they serve as accompaniments to rhythmical action and expression, although not so violent or intense in this particular as the drum or tambourin.

154. The *pianoforte* is a stringed instrument of still more extensive powers. Its strings are struck by means of hammers, and the wooden box enclosing the stringed apparatus is the resounding substance. To prevent the confusion that would arise by the too-long-continued vibration of the strings, a damper is mounted over every string, which is lifted by the same action that strikes the blow, and falls down again when the finger is removed from the key. Although the tones of the pianoforte are less sudden and more continuous than in the harp and guitar, they are still of an emphatic character, rendering beat and rhythm conspicuous along with the melody. The extensive popularity of the instrument has led to the composition of a large amount of music solely for its use. The mixture of melody and emphasis peculiar to it probably meets the taste of a large section of the listeners to music; but the preference given to the violin in the orchestra shows,

among other things, that the rhythmical beat of the pianoforte is considerably above what would constitute the golden mean. In dance music, both this instrument and the harp are extremely effective; the stimulus of their rhythm is not too great for the sobriety of the modern domestic dance. In combination with the voice, the pianoforte serves the purpose anciently served by the lyre, in giving emphasis and marking time, while it also contributes to the performance a melody of its own.

155. In slow and sacred music the pianoforte fails; and as it requires a constant percussion of its wires to sustain its full tones, its powers are most advantageously displayed in rapid and brilliant compositions, such as waltzes, quadrilles, variations of melodies, and sonatas. Beethoven and Mendelssohn have produced some of the most beautiful and classical music for this instrument.

156. In passing from the pianoforte to the *violin*, we make another step in that transition from rhythm and emphasis to pure melody which marks the succession of instruments above enumerated. The action of the bow being to produce a sustained tone, in place of a sharp and sudden beat, it is possible to subordinate rhythm to continuous flow of sound as far as we please. This is the grand characteristic advantage of the violin. Moreover, in the act of playing, the tact and skill of the player have the utmost possible scope, both in the handling of the bow and in the shortening of the strings. Whatever the ear may desire, it is possible for the hand to execute. In no other stringed instrument are the vibrations of the string under such perfect control. A kind of movement that seems, by its very nature, to be passing and momentary, is rendered continuous and durable. The transitions from note to note, which give the perception of time and rhythm, may be softened to almost any degree; while, on the other hand, it is possible to mark them with such emphasis and sharpness, as to produce all the effects of the other stringed instruments. The gay and animated dance may be supported with an equally animated accompaniment, and yet the instrument is capable of any degree of melody or solemnity.

157. The pianoforte, being an orchestra in itself, is liable to the defects of such an arrangement. But the violin has but a limited range, and each instrument is intended for only one single succession of sounds. The purity and clearness of the effect are in this way much better preserved. Probably, too, the compact body of the instrument forms a better resonant mass than the lumbering wooden structure of the piano. The action of the string upon the shell of the instrument is through

the bridge resting on the belly, and the belly and back are connected both at the edges and by a pillar in the middle. The sweetness of the tones may be supposed to depend partly on the form of the instrument, and partly on the material, but in what manner, seems not to be well understood. The gradual change that is wrought in the structure of all solid bodies by continual wear and tear, and by the motions of their particles consequent on shocks and agitation, seems favourable to their sonorous qualities, for it is remarked that violins improve with age.

158. To form a complete orchestra with the violin, four different sizes are required, corresponding to the four voices distinguished by musicians; namely, treble, contralto, tenor, and bass. With these it is considered that a perfect orchestra might be made up, capable of almost all the finest effects of the musical art.

159. The instruments above described are the leading examples of the stringed class. There are several others belonging to the same class that are now fallen into disuse, as the harpsichord and the dulcimer of the ancients. The *Æolian harp* is a peculiar example of the class. Placed before the narrow slit of a window, opened to about an inch or two, the concentrated wind-draught playing in the strings communicates sonorous vibrations of the sweetest natural melody. The same action may be sometimes observed in the wires of the electric telegraph. By listening near one of the posts, a very audible sound may be felt. In these cases the wind, or an air-current, is the striking body, and the delicacy of the stroke may be readily imagined to surpass every kind of blow from solid masses, even the most skilled performance of the violinist. Possibly instruments may yet be contrived in imitation of the Æolian harp, where a wind-blast may be the actuating impulse of the string-caused notes.

160. We come next to the *wind instruments*, in which the vibration of a column of air acts the part of the vibrating string in the preceding class, being the regulating medium, and the connecting link, between the primary impulse and the resonant mass.

161. The *Pan's pipes* we have already alluded to as the simplest form of wind instrument. A concentrated stream of air acts upon the sharp edge of the open end of the pipe, and by the strong friction, or impulse, imparts a vibrating state to the solid mass. At the same time a series of undulations are created within the pipe, whose rapidity depends on its length. These undulations act on the interior walls of the pipe, and

produce in its mass a corresponding note, or at all events regulate the vibrations caused by the blast, so as to make the two sets in unison. The note of each pipe would depend strictly on its length, if the undulations of the air had the entire control of the vibrations of the resonant tube.

162. It must never be forgotten, in the discussion of wind instruments, that there are very few examples of sound produced by a vibrating mass of air acting alone, or without being reinforced by resonance. We are therefore hardly in a position to appreciate the intrinsic feebleness of an aërial sounding substance. The most remarkable instance of a pure aërial sound is furnished by the thunder of the sky, which is no doubt a sound of immense power; but if the extent of the commotion is taken into account, the magnitude of the effect will not seem surprising. A thundery discharge is known sometimes to be several miles in length, and if a corresponding breadth and thickness of the agitated stratum be assumed, the bulk of air set in action will be many times greater than all the musical instruments of the world put together. With a solid resonance coextensive with the aërial agitation, the sound would be sufficient to rend the ears of a whole empire.

163. The *whistle* is a modification of the Pan's pipe, wherein the sound is produced with less difficulty, in consequence of a distinct direction being given to the air-blast. The sharp edge played upon by the current is expressly adjusted so that the stream passing through the narrow mouth of the whistle plays on it with perfect precision: in fact it is rendered impossible to miss the sound. The structure of the whistle thus yields a confirmation of the view given above of the action of the blast on the open pipe.

164. The whistle further differs from the simple pipe in producing a variety of notes. The manner of effecting this, in it and in similar instruments, is well known to be the virtual shortening of the tube by the holes pierced along the side. Since the condensation and rarefaction of the air are destroyed as effectually by a hole in the side as by cutting off the tube at that point, the lengths of the undulations are limited by the escape thus afforded into the outer air, and therefore the same sounds can be produced in a single tube as in a succession of tubes of different lengths. A range of notes, extending to an octave, are produced from a single pipe, and a second octave may be formed by increasing the stress of the blast till the column of the tube is broken up into its harmonic of half the length; and if, by a still greater exertion of voice, the harmonic undulation of one-fourth were brought into action, a third octave of notes might be given forth.

165. The *flute* is a wind instrument, differing from the whistle in the manner of exciting the sound. The air-blast is thrown upon the edges of a hole pierced in the side of the tube, in a way somewhat similar to the action in the Pan's pipe. As in the whistle and simple pipe, a sharp edge is obviously the place for concentrating the action of the current; and the vibrations produced in it are communicated to the mass of the instrument, and to the air-column within. The undulations of the air-column being the regulating power which determines the pitch of the note, their action upon the interior of the resonant mass of the tube must control the rate of its vibrations, even although we suppose these vibrations to be principally excited by the strong blast acting with a mechanical advantage on the edge of the hole. The air-stream from the mouth must tell directly both on the solid mass of the tube and on the air-column inside. The lowest note that the instrument can yield is made by blowing gently, and keeping all the holes shut with the fingers or keys. The upper notes are formed by successively opening the several holes, and by increasing the stress of the voice at each note. It requires a stronger mechanical impulse to produce the quicker vibrations of the higher parts of the scale.

166. The *octave flute* and *fife* are instruments of a smaller calibre than the concert flute, and therefore produce a series of notes higher up in the scale. It is to be observed of the flute, in common with the whole class of wind instruments, that these are truly and properly speaking instruments of melody, and not of beat or rhythm, being thus decisively contrasted with the class of stringed instruments. The nature of a wind-blast being to produce a continuous mellow sound, and not a sudden jerk or sharp stroke on the ear, wind notes coincide exactly with the very essence of melody, just as string notes coincide more particularly with the essence of rhythm. In wind instruments, the transitions from note to note, or the successive impulses of the air-blast, are the only means of indicating time or making beats; but such indications are very faint in comparison with the sharp strokes that excite stringed instruments into action. Hence in accompaniments to the dance or the military march the wind class are less applicable; and if employed at all, they must be used in conjunction with instruments of the other class. In military music, the fife and drum are the usual combination.

167. The brass instruments played by the mouth form a genus by themselves, and are all remarkable for the power, sharpness, and impressiveness of their sounds. They include the bugle, the cornopean or cornet-à-piston, the trumpet, the

Sax-horn, the French-horn, the trombone, the bass-horn, and the ophicleide. The simplest form of this class of instruments is seen in the *coach-horn*, which has a mouthpiece contracted to a narrow hole, and joining a tube which gradually swells out towards the other end. In observing the mode of bringing out the sound in such a structure, the principle of the sharp edge is manifestly detected. The air-blast acts, as in the cases already noticed, at once upon the solid tube and on its aërial contents; while the aërial undulations themselves act on the walls of the tube, and bring its vibrations into unison with theirs. That the friction of thin air is able to control the movements of particles of solid metal, seems at first sight strange, but the fact, nevertheless, is undeniable.

168. The *bugle* is the coach-horn curled round upon itself, so as to become more compact; but the principle of the structure is the same. Neither of the instruments can produce a great range of notes, inasmuch as the only means of varying the pitch is by altering the stress of the blast, one effect of this being to break up the air-column into its several harmonics. It is possible, however, to produce a few additional notes by changing the mode of the blast, or the mode of applying the lips to the mouthpiece. By thrusting the hand into the mouth of the tube, a further modification of the tones can be effected. But notwithstanding all these varieties of action, the range of the instrument is only about an octave. Were it not that the individual tones have great richness, and may be managed with a highly-melodious effect, the smallness of range of the instrument would reduce its performances to the extreme of meagreness and penury.

169. The *trumpet*, in its primitive shape, was exactly what we have called the coach-horn, being originally formed of a cow's horn, although afterwards made of metal. But the modern trumpet surpasses the bugle in range, in consequence of the adoption of crooks, keys, and valves, which serve the same purpose as the holes and keys of the flute; that is, they shorten at discretion the contained air-column, and thereby change the pitch of the notes.

170. The *trombone*, or the *sackbut* of ancient times, is a very powerful instrument, and may be described as a trumpet, the tones of which are regulated by a tube of brass sliding within another, so as to shorten or lengthen the column of air. An instrument made on this principle was discovered among the remains at Pompeii.

171. The above examples of the wind class of instrument are all formed on the principle of an air-stream playing on a sharp edge and on a contained air-column simultaneously; but

we have now to notice a different species, characterised by the use of reeds, the construction of these having been already mentioned. The *clarionet*, although not unlike the flute in its general structure, has a great superiority in the richness of its tones. The vibrations of the reed fixed in the mouthpiece seem to communicate a far more powerful agitation to the mass of the tube than it is possible to effect by blowing on the dead edge of the breath-hole of the flute. The mechanical advantage in the case of the reed may be supposed to be very considerable.

172. The *bagpipes* is a very ancient instrument of the wind and reed class, being of Arabian origin, although the Romans called it Etruscan. It has the peculiarity of keeping a bag of air constantly full, which is made to supply the instrument by being squeezed by the arms of the player. Like the clarionet, this instrument may sound very harsh if badly played; and great skill, as well as a good quality in the structure, is requisite to bring out the strong rich tones to perfection.

173. The greatest of all the wind and reed instruments is the *organ*, which is a vast collection of pipes brought into connection with a common wind-chest and bellows, whose blast supplies them with the exciting current. As each pipe plays only one note, a separate pipe is required for every note that it is wished to produce. But the organ is not content with one series of pipes extending over several octaves of the musical scale, and sufficing to make it as complete an instrument for melody or harmony as the piano; it comprises many such series, each having a peculiarity of effect distinguishing it from the rest, and constituting, as it were, a separate instrument. The more extensive the scale of the organ, the greater the number of these distinct sets of pipes. There is a peculiar machinery for bringing the different series into active connection with the bellows and keys called the *stops*—that is, each stop corresponds to a separate range of pipes, and, on being drawn, brings that range under the power of the performer. Thus by employing several stops simultaneously, the sound of many instruments is produced. The organ in the new church at Amsterdam contains fifty-two whole stops. Some of the stops are named from their imitating various instruments—as the *cornet*, the *trumpet*, the *bassoon*, the *flute*, the *cremona*. The most important stops of the more ordinary class are those named the *open diapason*, the *stopt diapason*, the *principal*, and the *fifteenth*. The compass of the individual stops may be extended from the lowest to the highest notes appreciable by the human ear, for this purpose it being requisite merely to enlarge or diminish the size of the pipes. Each pipe being

excited by a reed apparatus, the greatest possible mechanical advantage is allowed in the action of the blast upon the solid walls of the tube.

174. The organ is the extreme example of the instruments of melody and harmony, as contrasted with such as are conspicuous for beat and rhythm. Hence its characteristic effect is overpowering grandeur and solemnity, and its function in human life is to assist in public worship, or to produce vast and solemnising impressions. Anything approaching to gaiety or sparkling animation is totally excluded from the range of its powers.

THE HUMAN VOICE.

175. The organ of voice in the human subject, as well as in the inferior animals, is a wind instrument of very remarkable power, considering the simplicity of its parts. With a single tube it can produce a range of notes of from two to three octaves, depending in part on the different degrees of tension of the two edges or strings known as the vocal chords, which are acted on by the air-blast. These chords seem to have something of the character both of the string and of the sharp edge.

176. The organs of speech comprehend the lungs, the wind-pipe, and the mouth. The first serves as an air-chest to supply the current of air necessary to the production of sound; the second is a pipe extending from the lungs to the throat; and the cavity of the mouth, with the lips and tongue, are capable of modifying the sound into what is termed *articulate* sounds. The wind-pipe, reckoning from its upper extremity, consists of the *larynx*, the *trachea*, and the two *bronchial tubes;* the latter branching off from the lower end of the trachea, and proceeding, the one to the right, the other to the left lung. At the upper extremity of the larynx, called the *glottis*, sound is produced. It arises from the passage of the air from the lungs through a narrow slit called the *rima*, or *cleft* of the glottis (fig. 17), the edges of which consist of fibrous membranes called the *vocal chords*, by whose contraction so much tenseness or tightness is acquired, that they are capable of sonorous vibrations when a strong enough current of air is forced through the slit, either in inspiration or expiration, the sounds being more perfect in the latter case. When the vocal chords are not tense, the air passes through

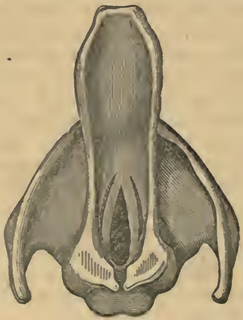

Fig. 17.

the glottis freely and silently, as in ordinary respiration. The glottis, with the cavity of the mouth, operate as a reed-pipe, and the different degrees of tension of the vocal chords has the same effect as different reeds in producing notes of different pitch.

177. The machinery requisite for the production of vocal sound includes, in the first place, the muscles of respiration, which are situated partly outside the chest, on the back and breast, and partly in the abdomen, as the diaphragm. The muscles that contract the chest, and force air outwards, are the most powerful of the two sets, whence arises the superior energy of the sounds of expiration, or of the outward current. For the stronger class of utterances a powerful blast is necessary, and hence the importance of a large powerful chest in vocal exertions.

178. The machinery in the vocal tube is chiefly the cartilages for stretching the vocal chords, and a series of connecting muscles capable of tightening or slackening the chords according to the note that is to be formed. The regulation of the note is left dependent on the different degrees of tightness and distance of the chords, and on the modifications of the tube itself, such as its being widened or constricted, lengthened and shortened. What is most certainly understood on this point is, that by stretching the vocal chords through the action of certain of the muscles, a high pitch is produced, and according as they are relaxed, the pitch is lowered. That a slack string yields a graver tone than a tight one is a well-known fact; but in ordinary strings the whole range that could be produced from this cause would be very trifling; in fact, hardly amounting, by any possibility, to two or three notes of the scale, whereas in the human voice a range of two octaves is quite usual. We must therefore suppose that the elongation of the vocal apparatus, which is sensibly felt as we ascend in pitch, is essential to the production of high notes. To produce a low bass note, the chin is lowered, and the neck contracted, so as to shorten the tube as much as possible, and alter the form of the cavity of the outlet; on the other hand, for an acute note, the windpipe is drawn out by elevating the head, and is thus rendered more slender and contracted in all its parts.

179. The whole of the *musical* apparatus of the voice is contained in the windpipe with its cartilages and vocal chords. By the various modifications of these, made under the guidance of the ear, we may produce all the degrees of pitch and intensity that come within the compass of the voice. The capacity of fine execution depends partly on the structure and

flexibility of the vocal organs, and partly on the form and structure of the resounding skull. But it is only in proportion to the delicacy of the ear or musical taste that exquisite organs of execution can be cultivated or adjusted to a high order of performance; a fact which holds in relation to every capacity within the range of the human constitution.

180. Although the voice shares the peculiarity of the whole class of wind instruments, in being more favourable to melody than to rhythm, it nevertheless has great power of rhythmical execution. This, however, in part depends on its articulate character, or in the use of language in connection with its performances, which gives it a manifest superiority over all instruments whatsoever.

181. The articulate capacity of the voice depends on certain additions to the organs already mentioned as supporting its musical power. It is found that the sound, in passing through the *mouth*, may have its character altered, not in respect of musical pitch or strength, but in a way to give it a distinguishable effect on the ear. If a person singing any one note of the musical scale with the mouth gaping open, were to continue the same note with the mouth nearly shut, the sound would be identical in its musical effect, but in respect of character or expression it would appear to be different. There would seem to be a change of shape in the sound itself. This peculiarity of sounds, which is dependent on the form and movements of the mouth during their utterance, is termed their articulate character; and sounds strongly marked with it are called *articulate sounds*. The musical and the articulate characters of sounds arise from different organs, and are governed by totally different principles. Their connection with the general framework of body and mind is also totally different. The windpipe sounds are combined into melodious successions, according to one class of feelings, while the mouth sounds are connected under the guidance of sensibilities which have very little in common with musical taste.

182. For articulate sounds, therefore, we have to refer to the construction and movements of the mouth. Every one knows its general form and parts, and we need only call attention to the movements performed in it. These are—*1st*, The movement of the lower jaw, which enlarges or contracts the height of the cavity, or its dimensions from above downward, and opens or closes the aperture of the teeth; *2d*, The movements of the cheeks, which distend or lengthen the mouth in the cross direction, and, along with the lowering of the jaw, open the cavity to its fullest dimensions; *3d*, The contraction of the ring of the mouth or lips, as exemplified in

the whistling position; *4th*, The elevations and depressions of the upper and lower lips, which combine with and modify the other movements; *5th*, The movements of the tongue. These are very various:—*1st*, It may be protruded outwards, or drawn in to the back of the mouth; *2d*, It may be bent or curled either up or down; *3d*, It has a free motion from side to side. By these motions the tongue can come into contact with any point in the cavity, and make the touch by different parts of its own surface.

183. All these movements tend to alter the shape of the mouth, and with this the expression of the sound which issues from it. Hence the possible variety of sounds that may arise is unlimited. The distinguishable sounds, however, are not very numerous. They are arranged into various kinds:—

184. *1st*, We have what are called the *vowel* sounds. When all the parts of the mouth are in one fixed position, giving a free opening outwards, and remain fixed during the emission of a sound, so as to exercise no other influence than arises from the mere shape of the cavity, a vowel is produced. Thus, in sounding *ah*, the mouth is opened, and the jaws, cheeks, lips, and tongue are fixed dead in one posture; so in sounding *uuh*, the posture, though different from the former, is still a quiescent or dead posture. By altering the shape, the sound is altered; but so long as it is an unalterable shape, a vowel is the result. The vowels that are most markedly distinguished from each other, are such as arise from the most widely-different arrangement of the parts of the mouth. The five vowels, *ah*, *ee*, *ay* (*say*), *oh*, *uh*, are the five most distinct sounds resulting from the various extreme positions of the organs, and may be called the five fundamental vowel sounds, having a greater difference from each other than any one of them has for any other sound distinct from them. Thus the English vowel sound *awe* arises from a middle position between *ah* and *oh*. The English sound of *i*, as in *sit*, is very little different from the fundamental *ee*; *set* is very near *say*; and even *u* in *but* is but one remove from the same sound. The *a* in *sat* is a modification of the fundamental *ah*. Every one of these sounds can be varied by a slight shading, so as to produce several that a fine ear can distinguish. In fact no two nations pronounce similar vowels exactly alike, and even in the individuals of the same nation slight differences are very common: sometimes the people of one province can be distinguished by the shade that they give to the fundamental letters of the alphabet. Thus the Scotch sound of short *i*, as in *sit*, is often too near the *ay* sound, whereas in correct English pronunciation it should be nearer the *ee*.

185. But the varieties of vowel utterance can be immensely extended by combinations of vowels, or by changing from one to another within the same breath, as in *boy*. This gives rise to what are called *diphthongs*. There are some of these diphthongs so natural and easy, that they are adopted as regular alphabetical sounds, on which differences of words are founded. In English there are three proper diphthongs: these are the sounds in *sigh*, *now*, *boy*. The first is a combination of *ah* and *ee;* the second of *oh* and *uh;* the third of *oh* and a sound approaching to *ay*. There are other diphthongs less perfect than these, or in which the sounds do not run together so completely. Thus the *ua* in *quake*, the *we* in *Tweed*, are regarded as diphthongs less pure than the others.

186. 2*d*, Of the class of sounds called *consonants*, a great many divisions have been made. They differ from the vowels in requiring some of the parts of the mouth to perform particular movements, in order to their being uttered. A certain play of the tongue, teeth, or lips, is necessary to each of them. This play may vary from the mere quiver of the tongue in sounding *s*, to the forcible shutting off of the sound by the sudden closure of the lips in *p* final. The sounds *p*, *t*, and *k*, are connected either with sudden closures or with sudden explosions of the sounding emanation, and are therefore called *mutes*, and also *explosive* letters: *p* is formed by the lips, *t* by the point of the tongue striking the roof of the mouth near the teeth, *k* by the back part of the tongue striking the back part of the roof. Of these, *p* is the easiest to sound, and the first learned by children, and *k* the most difficult. The *p*, being formed by the lips, is called a *labial*, *t* a *palatal*, and *k* a *guttural*, or throat-formed letter. And as all the consonants are formed more or less nearly in one of these positions, a general division can be made of them into labials, palatals, and gutturals. Six distinct labials are enumerated, depending on different ways of sounding with the lip closure. The mute or explosive *p* has been mentioned; next to it is *b*, produced by a less violent closure, which allows the voice to be heard during the act, as any one will feel by sounding *cup* and *cub*. The third labial is *m*, which is still farther removed from the sudden extinction occurring with the *p;* a free communication is opened with the nose for the egress of the air, and the sound can be made continuous like a vowel; in other words, we have the humming sound; this is the *nasal* labial, while *b* is called the *vocal* labial. The fourth labial is *f*, produced by the upper teeth and the lower lip coming together, and the breath passing through them without voice; this is the whispered or *aspirate* labial. When the vocal chords are tightened

up, and the hard sound of the voice sent through this closure, we have *v*, or a second vocal labial, called the vocal aspirate. Lastly, a sound may be sent through the closed lips, making them vibrate or shake like a reed, as in the sound *prr;* this is the *vibratory* labial, or the labial *r*. A similar series can be described in the palatals. The mute being *t*, the vocal is *d;* the nasal are *l* and *n;* the aspirates are *th* (*th*umb), *s*, *sh*, arising from slightly-differing positions of the tongue in its contact with the palate: the vocals, or audible forms of these, are *th* (*thy*), *z*, *j;* the vibratory palatal is the common *r*. The gutturals likewise show the same list of varieties. First, *k* mute; then the vocal *g;* the nasal *ng*, a simple sound, though spelt in our language with two letters; the aspirate *ch*, as in *loch*, together with the fainter form *h;* the vocal aspirate *gh* unknown, and almost unpronounceable by us; and the vibratory *ghr* occurring as a burr in some people's utterance. This classification, which was first proposed by Dr Arnott, may be summed up in the following table:—

	Labials.	Palatals.	Gutturals.
Mute, . . .	*p*	*t*	*k*
Vocal, . . .	*b*	*d*	*g*
Nasal, . . .	*m*	*l*, *n*	*ng*
Aspirate, . .	*f*	*th*, *s*, *sh*	*ch*, *h*
Vocal Aspirate, . .	*v*	*th*, *z*, *j*	*gh*
Vibratory, . .	*pr*	*r*	*ghr*

187. Besides these, there are two letters essentially of the nature of vowels, but having in many cases the force of consonants. These are *w* and *y;* the one a prolonged or double *u*, the other a prolonged *e*. The peculiar effect of each is brought out when followed by another vowel, so as to make a diphthong. The *w* has a labial character, the *y* a guttural.

188. The nasal letters may be so attenuated as to lose the character of consonants, and merely give a nasal twang to the vowel adjoining. This is the case in the French pronunciation.

189. Speech is generally a mixture of vowels and consonants. The utterance most easy to sustain, and most agreeable to the ear, is formed by a vowel and consonant alternating. Vowels alone produce too feeble an impression to make a distinct language. As a general rule, abrupt sounds have the most marked effect on the ear; so that a mixture of these is necessary to make a clear and intelligible series of sounds. Hence the mute consonants *p*, *t*, *k*, have a high value, as characteristic and unmistakeable letters; but the hissing sound of *s* is remarkable for its piercing effect on the ear, and for its being

so peculiar and distinct, that no other sound can be confounded with it; and it is therefore an exceedingly useful member of the alphabet. The same remark, in a less degree, applies to *r*, which leaves a vivid impression, and is not easily mistaken for any other sound. The aspirates generally, *f*, *sh*, *ch*, *h*, have a certain amount of the hissing peculiarity, but none of them are so intense as the pure *s*. They have all, however, a distinct and sharp effect on the ear.

190. The three mutes, *p*, *t*, *k*, and the three vocal sounds corresponding, *b*, *d*, *g*, cannot be pronounced without the help of some vowel; hence in their pure form they are abstractions rather than realities. Almost all the others permit of themselves a constant passage of the breath, and can therefore be sounded without the addition of vowels. Thus *m*, *n*, *l*, *r*, *ng*, *f*, *s*, &c. can all be sounded each by itself alone, although the addition of a vowel will in general make the exercise more easy. Thus *mmee* is easier and pleasanter than *mmm*. The passing into a vowel is a passing from a forced to a free posture of the parts of the mouth. But as these letters can be sounded with more or less difficulty by themselves, a number of them have been called *semivowels*, or we might call them thick or viscid vowels. They have a middle character between the vowels and the six consonants above-mentioned. They demand a less violent exertion than the abrupt consonants, but a greater exertion than the vowels.

SPEAKING MACHINES.

191. From the time that the statues of Memnon emitted their mystical tones on the banks of the Nile, and the oracular responses were delivered at Delphi, through the period when a speaking head was exhibited by the pope, towards the end of the tenth century, and others afterwards by Roger Bacon and Albertus Magnus, various surprising efforts have been made to produce a machine capable of articulating human words and sentences. The record left us concerning the Egyptian statues is by far too scanty to afford basis even for a probable conjecture; and with respect to the oracle at Delphi, the cave of Trophonius, and the like, we have every reason to suppose that the sounds emitted were merely those of some confederate, rendered more surprising by calling in the aid of acoustic principles in the construction of the oracular temple. Again, the speaking instruments of the middle ages were simple combinations of pipes and stops concealed by an external semblance of a human head, and capable of uttering only a few simple syllables.

192. It is but recently that ingenuity, aided by the numerous mechanical facilities of the present day, has been able to complete a machine capable of simulating the human voice in a tolerable manner. In 1779, Kratzenstein of Petersburg, and Kempelen of Vienna, constructed machines which pronounced articulately letters, words, and phrases. By adapting sliding tubes to a reed, Mr Willis of Cambridge has recently succeeded in the enunciation of the vowels *i*, *e*, *a*, *o*, *u* in order, by drawing out the tube gradually during the passage of a current of air through it from the bellows of an organ; on farther extending the tube, the same vowels, after an interval, are obtained in a reverse order; and on continuing to extend the pipe, the same series of vowels are, after similar intervals, obtained alternately in the direct and inverted order.

193. Of all speaking machines, that lately finished by Faber, which engaged him for twenty-five years, is the most perfect. It is constructed as like as possible to the human organs of speech. An elastic tube represents the larynx, a pair of double bellows the lungs, and a piece of caoutchouc the tongue. By means of a set of fourteen stops, like those of a pianoforte, motion is communicated to internal levers, which produce the pressure and movements necessary for modifying the simple vowel sounds into the various kinds of labial, nasal, guttural, and lingual consonants. So complete is the machine, and so entirely is its operation under the control of its inventor, that it can pronounce a variety of words and phrases in different languages, with a wonderfully-perfect articulation and intonation of voice. There is no doubt that the machine may be much improved, and more especially that the *timbre* of the voice may be agreeably modified. The weather naturally affects the tension of the India-rubber; and although the inventor can raise the voice or depress it, and can lay a stress upon a particular syllable or a word, still, one cannot avoid feeling that there is room for improvement. This is even more evident when the instrument is made to sing; but when it is remembered what difficulty many people have to regulate their own *chordæ vocales*, it is not surprising that Mr Faber has not yet succeeded to his wishes in this department.

ORGANS OF HEARING.

194. The organs of hearing are divided into three parts—the external, middle, and internal ear. The *external* ear consists of an external cartilaginous plate, curved in various directions; it is what in common language is called the ear or conch, *c*. The *external auditory passage*, *m*, or funnel-shaped canal, extends inwards about an inch. The *middle* ear consists of the cavity called the *tympanum*, or drum, *t*, and its *membrane*, *d*, which bounds it on the external side, at the inner end of the external passage. This cavity contains a machinery of four small bones, *b*, called the *hammer*, the *incus*, the *orbicular bone* (a very small one), and the *stirrup;* their Latin names are the *malleus*, the *incus*, the *os orbiculare*, and the *stapes*. The *internal* ear, or *labyrinth*, contains the several cavities named the *vestibule*, *v*, the *cochlea*, *k*, and the *semicircular canals*, *s*.

Fig. 18.

195. On the inner side or wall of the cavity of the tympanum, are two small holes, or foramens, the upper being named the *oval foramen* (*fenestra ovalis*), and the lower the *round foramen;* the former of these foramens communicates with the vestibule, and the lower with the cochlea, and both are closed by membranes. The membrane of the tympanum is similar to the top of a common drum, and can be kept in any required degree of tension by means of two small muscles that respectively stretch and relax it, called the *tensor* and *laxator* muscles. The four little bones are articulated in order into one another; the handle of the malleus is inserted into the membrane of the drum, and the sole of the stirrup is intimately connected with the membrane of the oval foramen. The ex-

tremities of the semicircular canals open into the vestibule; the cochlea is like a spiral shell, such as one of the elongated land-shells called a helix, and is divided into two compartments by a spiral thin partition in the direction of its length, excepting a small portion at its apex, at which there is a communication between these divisions; one of the divisions at its base opens into the vestibule, and the other communicates with the tympanum through the round foramen. In the interior of the bony labyrinth—that is, in the vestibule, the semicircular canals and the cochlea—is the *membranous labyrinth*, which is a membranous structure following the windings of the bony cavities, and having, therefore, nearly the same shape. In this membrane the ultimate branches and fibres of the nerve of hearing, *n*, are distributed like a fine network, and the membrane is surrounded on all sides with the liquids which fill the cavities of the labyrinth.

196. There is a communication between the cavity of the drum and the mouth, by means of a narrow canal called the *Eustachian tube*, *e*, terminating in the posterior nares near the pharynx; it is trumpet-shaped, the narrow end being next the drum.

197. The sensation of sound is produced by a series of different actions, commencing with the agitation of the *membrana tympani*, and ending in the excitement of the nerve of hearing. The sound passes through three different substances, and these are so chosen and adjusted, as to make the ultimate effect as perfect as possible. In the first place, it is found that nothing is so well adapted to receive the sonorous undulations of the air as a tight membrane or drum-head, like the membrane of the tympanum; in no other way could aërial impulses communicate themselves with so little loss. In the next place, the agitations of a membrane may be most effectively imparted to another body, if that body is a solid, and accordingly a framework of a compact bony structure receives the vibrations of the membrane of the tympanum at one end, and communicates them at the other to a liquid mass contained in the closed chamber of the labyrinth. The stirrup bone, by lying tight upon the membrane that closes the oval foramen of the labyrinth, communicates its own vibrations to the liquid contents of the cavity; in other words, a series of undulations are excited in the liquid where the nerve of hearing lies spread out on the membranous labyrinth. The undulations of the liquid are thus a series of compressions of the soft labyrinth and of its imbedded nerve-fibres; and this squeezing of the nerve-fibres is what constitutes their stimulus preparatory to the sensation of hearing. The effect ultimately to be brought

about being the successive compressions of the nervous net-work of the ear, corresponding to the undulations of the air without, and it being impossible to effect this by the direct action of the air, which would be too feeble for the purpose, an intermediate structure is contrived, consisting of membrane, solid and liquid, the first being the thing best adapted to receive the aërial impulses, and the last being the only means of producing, in a sufficiently delicate way, the effect on the nerve, while an intermediate solid framework is equally requisite to connect the vibrations of a membrane with the undulations of a liquid. The ultimate action on the nerves is precisely the same as in the sense of touch, being a mechanical pressure on a membrane where the nerves are imbedded, and equivalent to a pressure on the nerves themselves. But in the sense of hearing, the pressure is of a far more delicate kind; anything approaching to a *solid* compression of the membrane of the auditory nerve would probably cause unutterable agony, and the notion of a sound as of the crashing of the universe.

198. The muscles of the drum of the ear are an essential part of the organ, as the muscles of the eyeball are of the eye. The movements effected by the muscles are principally the tightening and relaxation of the membrane of the tympanum, *d*, to suit the different degrees of strength of the sound. The more relaxed the membrane, the feebler the impression made in it and on the ear; while, by tightening it, a much sharper effect is produced. The immediate effect of any sonorous impression is to send a nervous stimulus to the muscle that stretches the membrane of the tympanum, in order that this last may be better prepared for the reception of the sound, and according as the effect is grateful to the sense of hearing, the reflex action on the muscle is the more sustained. If the sound is too strong, the membrane of the tympanum is relaxed; if too weak, it is tightened, in order to magnify the effect; just as in the case of seeing, excess of light causes a contraction of the pupil of the eye, and a deficiency a corresponding enlargement. But since the muscles are sensitive as well as the membranous surface of the labyrinth, a series of muscular sensations are mixed up with the auditory sensations proper, and impart their own character to the feelings communicated through the sense of hearing. A constant relation is kept up between the auditory impressions and the muscular apparatus that governs the movements of the *membrana tympani*, and regulates its exposure to the sonorous vibrations of the air, and thus a complicated result is produced in the end, half auditory and half muscular.

199. The sense of the direction of sounds, which at best seems very imperfect, especially when we compare the ear with the eye, depends partly on the motion of the membrane of the tympanum, and the feeling arising from its muscular adjustment, and partly on the motion of the head. There is a certain position of the head that gives us the feeling of the sound being direct, or straight from the opening of the ear, while in all other positions more or less of obliquity is conceived. This is purely a feeling of the muscles, and the sense of it resides properly in the cavity of the tympanum, or with the apparatus of bones and muscles enclosed there: it is exactly as in the case of a stroke upon our body, the direction of which is known from the course of the movement that follows it. If the waves of air go straight towards the membrane of the drum, the vibrations of the membrane will give a corresponding straight course to the vibrations of the bones of the drum; and in like manner a slanting direction in the one will make a slanting direction in the other, and of this the muscles will be cognisant, just as the muscles of the leg are cognisant of all movements impressed upon it. In fact the vibrations of the small bones, which are destined ultimately to leave an impression on the auditory nerve, will, on the way, impart impressions of a different kind through the muscles that are attached to them for the regulation of their movements.

200. The individual character of so complex an instrument as the ear must depend on the peculiarities and modifications of its several parts, and thus very great differences may occur in the nature of the auditory sense. The variations in the delicacy and refinement of the membrane of the tympanum, the bony and muscular apparatus of the middle ear, and the nervous filaments of the membranous labyrinth, respectively, will constitute ears of different kinds of merit and perfection. A detailed account of the varieties of sounds, according to the distinctions that the ear aids us in perceiving, will be the best means of enabling us to judge of the specific qualities that may belong to the ears of differently-formed individuals.

CHARACTER AND VARIETIES OF SOUNDS.

201. In discriminating sounds, we rely partly on our sense of hearing, and partly on our knowledge of the instruments or machinery causing them; and an accurate account of their varieties being important in many points of view, an attempt at this will form the most appropriate conclusion to the present treatise :—

202. *First*, Tune, or *Pitch*. The nature and cause of this

peculiarity have already been repeatedly touched upon. Being dependent on the dimensions of the sounding body, or that portion of it acting as the regulator of the sound, it is measured by the number of vibrations made in each second by the particles of the instrument, and by the number of impulses given to the membranous labyrinth of the inner ear, and through it to the ramifications of the nerve of hearing. The rate of rapidity of these impulses is distinctly perceived by the sentient mind, although not alike by all minds. To have a keen and delicate perception of this particular property, is one of the very first requisites of a musical ear. It is probable that all parts of the ear are concerned in giving such a sensibility. The delicacy of the membrane of the tympanum, the fineness and susceptibility of the muscular and bony apparatus of the intermediate ear, and the sensitiveness of the nerve-fibres to the peculiar effect of a repetition of impulses, and to the degree of rapidity of that repetition, would each contribute to the perfection of the musical ear, apart from the inward feelings of the mind itself. The same power of discrimination that serves to determine differences of pitch or tone, would serve also to discriminate between the equal succession characteristic of a musical note and the unequal and irregular succession of unmusical sounds. There is a great satisfaction communicated by a recurrence of beats at equal intervals, but different persons are liable to it in very different degrees. Some enjoy the succession that exists in the musical note, which seems to form a continuous stream, and others prefer the more slow and palpable beats of one of the instruments of strongly-marked rhythm, which is naturally the most exciting of the two, the excitement, however, in all probability depending on the intensity of the strokes. Excessively high or acute sounds, if at the same time they possess any degree of intensity, are extremely painful and piercing; while grave sounds have generally an indifferent, if not an agreeable effect.

203. *Second, Intensity.*—This means literally the violence of the blow given by a vibrating medium in a state of sonorous excitement. The more powerful the undulations that strike on the drum of the ear, the more powerful the impulses that compress the nerve-fibres of the membranous labyrinth, and the more intense the sensation communicated inwards to the auditory centre of the brain. Up to the point of producing some disorganizing effect on the system, we generally prefer strong sensations to weak ones, and hence intensity may be considered as a desirable property of sound, if in other respects it is of the agreeable kind. The exhaustion or fatigue of the nerves and other parts of the ear is the limit to the enjoyment

of strong sounds. We have already seen that the instruments of the metallic kind yield the most powerful tones; and in the unmusical uproar of busy life, all kinds of work and traffic in articles of metal are noisy and fatiguing to the ear. When sounds are overpoweringly intense and hard, they produce not only pain, but positive fright and panic, if people have not been disciplined to endure them. The ringing of church bells close at the ear, or the firing of ordnance, are apt to deafen and discompose the listeners. To persons deriving enjoyment from sounds, but apt to be pained and fatigued by such as are intense, the calmer and quieter class of utterances are preferred—the ripple of the waters, the gentle breeze, or the hum of industry in the distance. In the silence of nature's solitudes, gentle sounds make a deep but not fatiguing impression.

204. The suddenness of sounds is connected with their intensity, as marking a contrast between two successive states of nerve, one little excited, and the other much. In producing terror and mental discomposure, or any of the other secondary effects of sounds, suddenness of action is very effective. A *prolonged*, intense sound will wear out the organs, but it does not naturally agitate the system to the same degree as one that is sudden.

205. *Third*, *Clearness*, or purity.—A clear sound is one that has a distinct, uniform character, and is not choked, or encumbered with confusing ingredients. A clear-toned instrument is one that yields, in their most unmixed and perfect shape, the notes that it is intended to produce. The perception of tone or pitch depends very much on the clearness of the sound, and we judge of clearness by our ability to discern the exact character of what is intended. In instruments, the purity of the sound must depend very much on the texture of substance employed. Silver is the clearest-toned metal. Glass, from the uniformity of its texture, yields remarkably clear tones. In instruments of wood, a hard and uniform tissue is indispensable. In the human voice, *musical* clearness and *articulate* clearness depend upon totally different qualities. The first arises from the structure of the larynx and the constitution of the resounding skull; the second depends upon the sharpness and suddenness of the articulate actions of the mouth. In every kind of expression clearness is an indispensable virtue, and the merit of musical or articulate performances must be exactly in proportion as the effect intended stands out apart from other effects not intended.

206. *Fourth*, *Simplicity* and *Complexity*.—This obviously means the contrast between few and many sounds concurring at the same moment. All undulatory actions may be exceed-

ingly complex without mutual destruction. The same surface of water may be agitated by numerous crossing waves; but each will proceed unimpaired to its destination, the same as if no others existed. So in sounds, the membrane of the ear may be affected with several series of vibrations, which it will transmit, with all their primitive distinctness, to the fibres of the nerve of hearing; and this nerve may also transmit them, without confusion, to the auditory centre. But in the mind itself the distinctness is not so well preserved: some degree of fusion takes place; and this may be grateful or otherwise, according to the nature of the separate sounds. Sometimes these may be such as to produce an agreeable concurrence or harmony, as formerly explained; at other times they give jarring impulses, and cause discord and pain. The essence of discord, in the innermost recesses of soul, is exactly what it means in its ordinary signification—pulling opposite ways, *distraction*. Sometimes a multitude of sounds will fall on the ear, and be perfectly indifferent to one another, neither concurring nor contradicting in the impulses they stimulate. This is the most common case in the ordinary sonorous din of life.

207. *Fifth, Volume.*—In order to understand fully the subject of complex sounds, we must consider them in the point of view of volume or magnitude. When the sounding body is a large, extensive mass, the sound is said to be voluminous. The vibrations of a great number of different points pour themselves all together upon the ear. This increases the effect and influence of the sound, without causing a pure increase of strength or intensity. The waves of the sea, the thundery discharge, the howling winds, are all voluminous sounds, and the effect of resonance and echo is to give this character to sounds originally of limited nature.

208. The effect of volume on the ear is analogous to the effect of expanse upon the eye—it gives a sensation of largeness and extension. The stimulus of the ear from so many directions at once produces an attempted sweep of the exposed surface round the whole, through the muscular movements of the tympanic apparatus, and this gives the feeling of dimension on every side. The susceptibility to this peculiar feeling is exclusively muscular, and is likely to be common to all the parts of the muscular system, and especially to be shared with the muscles of the eye, which have a parallel function.

209. It happens, as a matter of necessity, that grave sounds are voluminous. They require a large extent of sounding mass for their production, and hence the impulse they give to the ear must be multitudinous.

210. *Sixth, Timbre,* or *Quality.*—By this we mean the peculiar

distinction between the sounds of different instruments when they are precisely the same in pitch, intensity, clearness, and volume, and depending evidently on the nature of the sounding material. The notes of the violin have one quality, those of the clarionet a different quality, and even between instruments of the same nature we may detect differences. No two human beings have precisely the same quality of voice, and we apply a great many epithets to distinguish the merits and demerits of individual voices, apart from their power of producing certain tones, or a peculiar amount of strength or clearness. The virtues of sweetness, richness, mellowness, refer to the property we are now considering.

211. What peculiar difference is impressed upon the vibrations of the air, to convey to us the feeling of distinctness of quality, has not been precisely ascertained.

212. *Seventh, Expression.*—This relates particularly to the articulate quality of sounds, or to the effect produced upon us by the human voice, according to the shape given to the mouth during their utterance. It has been already explained that the varieties of the vowels are dependent on this circumstance. The effect of volume, or of sound proceeding from an expanded surface, is here refined upon, so as to give character and meaning to vocal utterance. It furnishes a faint resemblance to the power of the eye in ascertaining the shapes and proportions of visible objects. The difference of action in the sounding of *ah* and *ooh* is a difference in the area of the sounding stream issuing out of the mouth, and probably also involves some distinction in the intensity and direction of its different parts. But this portion of the subject is extremely obscure.

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